EGAS MONIZ SCHOOL of HEALTH & SCIENCE | INSTITUTO UNIVERSITÁRIO EGAS MONIZ

INSTITUTO UNIVERSITÁRIO EGAS MONIZ

MESTRADO INTEGRADO EM MEDICINA DENTÁRIA

Managing Surgical Complications in Oral Implantology: A Focus on Surgical Complications and Their Management

Trabalho submetido por

Yacine Matmer

para a obtenção do grau de Mastre em Medicina Dentária

Junho de 2025

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Trabalho orientado por:

Prof. Doutor Jorge Rebola

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ACKNOWLEDGEMENTS

I would like to express my heartfelt gratitude to the **Egas Moniz Institute** for offering me the opportunity to pursue the equivalence of my foreign dental degree. This academic recognition has been a pivotal milestone, enabling me to continue my professional journey in Europe. I am truly thankful for the trust and support extended to me by this esteemed institution.

My deepest appreciation goes to my supervisor, **Prof. Doutor Jorge Rebola**, whose guidance, availability, and expertise were invaluable throughout the development of this thesis. His support has been essential to the successful completion of this work.

I also extend my sincere thanks to **all the professors of the dental clinic** for creating a dynamic and supportive environment that greatly enhanced my clinical and academic skills.

A special mention goes to **Dr. Guerreiro Eduardo** and **Dr. Ana Vieira** for their dedicated teaching and continuous encouragement throughout the program.

To the **clinical staff**, thank you for your professionalism, warmth, and dedication to patient care, which made my clinical experience enriching and highly motivating.

To my **parents**, *Lounes Matmer* and *Benali Louisa*, your unconditional love, sacrifices, and unwavering belief in me have been my anchor and my strength.

To my **siblings** — *Samir, Naima, Kahina*, and *Célia* — thank you for your constant encouragement, love, and inspiration throughout this journey.

To my **friends** — *Meziane, Djamel*, and *Zakaria* — I am grateful for your presence, motivation, and the countless shared moments that lightened this path.

To my **classmates**, thank you for making this academic journey intellectually stimulating and personally fulfilling.

In conclusion, this thesis is the result of the combined support, knowledge, and kindness of all those mentioned above. I am deeply grateful for the role each of you played in my academic and personal development.

RESUMO

A implantologia oral é um método amplamente utilizado e eficaz para restaurar a função e a estética em pacientes edêntulos. Apesar dos avanços nos materiais e nas técnicas cirúrgicas, o procedimento continua sujeito a várias complicações, nomeadamente de natureza vascular e neurológica. Estes eventos adversos podem comprometer o sucesso do tratamento e a segurança do paciente.

Esta dissertação analisa as principais complicações cirúrgicas intraoperatórias e pós-operatórias, com ênfase em hemorragias e lesões nervosas envolvendo o nervo alveolar inferior, o nervo lingual e o nervo mentoniano, assim como estruturas arteriais como a artéria alveolar posterior superior e a artéria submentoniana. Ilustrações anatómicas e discussões detalhadas são usadas para identificar e contextualizar as zonas de risco.

São apresentadas classificações das complicações com base na gravidade, reversibilidade e necessidade de intervenção, juntamente com uma revisão dos fatores contribuintes, como o planeamento radiográfico inadequado e erros técnicos. Também se aborda o papel da tomografia computorizada de feixe cónico (CBCT) e dos fluxos de trabalho digitais na antecipação e minimização dos riscos.

Este estudo visa fornecer recomendações práticas para a prevenção e gestão de complicações, contribuindo para protocolos cirúrgicos mais seguros em implantologia dentária.

Palavras-chave: Implantologia; complicações cirúrgicas; hemorragia; lesões.

ABSTRACT

Oral implantology is a widely adopted and effective method for restoring the function and aesthetics of edentulous patients. Despite the advances in materials and surgical techniques, the procedure remains susceptible to various complications, particularly of vascular and neurological nature. These adverse events can significantly impact the success of treatment and patient safety.

This thesis examines key intraoperative and postoperative surgical complications, focusing on hemorrhage and nerve injuries involving the inferior alveolar, lingual, and mental nerves, as well as arterial structures such as the posterior superior alveolar artery and submental artery. Through anatomical illustrations and detailed discussion, risk zones are identified and contextualized.

Classifications of complications, based on severity, reversibility, and intervention needs, are presented, alongside a review of contributing factors such as poor radiographic planning and technical errors. The role of Cone Beam Computed Tomography (CBCT) and digital workflows in anticipating and minimizing risks is also explored.

This study aims to provide practical recommendations for preventing and managing complications, contributing to safer surgical protocols in implant dentistry.

Keywords: Implantology; surgical complications; hemorrhage; injuries.

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I. Introduction

The aim of this thesis is to present a structured review of the major surgical complications encountered in oral implantology, with a focus on their anatomical basis, prevention strategies, and clinical management. Hemorrhagic and nerve-related complications are emphasized due to their frequency and potential severity. Adapted anatomical diagrams are incorporated to support the identification of risk zones, and practical recommendations are provided to enhance surgical safety and improve patient outcomes.

Recent advances in imaging, particularly the introduction of Cone Beam Computed Tomography (CBCT), have greatly improved the surgeon's ability to visualize critical anatomy. These three-dimensional tools enhance diagnostic precision and allow for safer planning and placement of implants. Moreover, classification systems of surgical complications have been developed to help clinicians predict, prevent, and manage adverse events. These classifications consider parameters such as severity, reversibility, and preventability, which aid in the selection of appropriate interventions (1)

Among the most critical of these risks are hemorrhagic and neurological complications, which can have lasting impacts on both the outcome of the procedure and patient quality of life. These complications are frequently related to a lack of anatomical knowledge or insufficient preoperative planning. The posterior mandible presents particular challenges, where vital structures such as the inferior alveolar nerve, mental foramen, and lingual nerve must be precisely identified and avoided. In the maxilla, arteries such as the posterior superior alveolar, infraorbital, and greater palatine arteries pose a risk of bleeding if inadvertently injured(2) (3)

Over the past several decades, oral implantology has established itself as a reliable and well-accepted solution for the rehabilitation of edentulous and partially edentulous patients. With implant survival rates exceeding 90% in long-term studies, dental implants have become a cornerstone of restorative and prosthetic dentistry. However, like all surgical procedures, implant placement carries inherent risks that must be carefully managed (1) (4)

1.1. Overview of Implantology

Dental implantology has undergone significant evolution over the past century, transitioning from rudimentary tooth replacement methods to sophisticated, technology-driven procedures. In the early 20th century, various materials and techniques were experimented with, but it wasn't until the mid-20th century that substantial progress was made. The pivotal moment came with the discovery of osseointegration by Per-Ingvar Brånemark in the 1960s, which demonstrated that titanium could form a direct bond with bone, providing a stable foundation for dental prosthetics.

Advancements in materials science and surgical techniques have since propelled the field forward. The introduction of biocompatible materials, such as titanium and zirconia, has improved the success rates and longevity of dental implants. Moreover, the integration of digital technologies, including computer-aided design and manufacturing (CAD/CAM), cone-beam computed tomography (CBCT), and 3D printing, has enhanced the precision of implant placement and customization. These innovations have not only improved clinical outcomes but have also expanded the applicability of dental implants to a broader patient population.

Today, dental implants are considered a reliable and effective solution for tooth replacement, with high success rates and patient satisfaction. The continuous evolution of implantology reflects the dynamic interplay between clinical practice and technological innovation, underscoring the importance of interdisciplinary collaboration in advancing patient care (5).

1.2. Definition of Osseointegration

Osseointegration is defined as the direct structural and functional connection between living bone and the surface of a load-bearing implant, typically made of biocompatible materials like titanium. This process is characterized by the absence of intervening soft tissue, allowing for a stable and enduring bond. Clinically, an implant is considered osseointegrated when there is no progressive relative movement between the implant and the bone with which it is in direct contact. This stability enables the implant to withstand the mechanical forces of daily oral functions such as chewing and speaking, ensuring long-term success of the dental prosthesis (6).

1.3. Principles of Osseointegration

The foundational principles of osseointegration were established in the 1960s by Dr. Per-Ingvar Brånemark, who discovered that titanium could form a direct bond with bone tissue without the interposition of soft tissue. Subsequent research has highlighted that the success of osseointegration is influenced by various factors, including the surface properties of the implant. Surface roughness and bioactivity play crucial roles in promoting bone cell attachment and proliferation. Advancements in implant materials, such as the development of titanium alloys and surface modifications, have been shown to enhance the biological response of surrounding tissues, leading to improved integration and stability of the implant (7).

1.4. Stages of Osseointegration

Osseointegration is a dynamic, multi-phase process through which a dental implant becomes firmly anchored within the jawbone. This biological integration unfolds over several key stages:

1. **Initial Healing Phase**: Immediately following implant placement, a blood clot forms around the implant site, initiating the healing process. This phase involves an inflammatory response that clears the surgical site of debris and sets the stage for new tissue formation (8).
2. **Bone Formation Phase**: Osteogenic cells migrate to the implant surface, leading to the formation of new bone matrix. This newly formed bone begins to bridge the gap between the implant and the existing bone, establishing initial mechanical stability (8).
3. **Bone Remodeling Phase**: Over time, the initial woven bone is replaced by more organized lamellar bone, enhancing the strength and stability of the implant. This remodeling process adapts the bone structure to better withstand functional loads.
4. **Maturation Phase**: The bone continues to remodel and adapt to the mechanical stresses placed upon it, ensuring the long-term success and functionality of the implant. This phase culminates in the establishment of a robust and durable bone-implant interface (8).

Understanding these stages is crucial for clinicians to optimize treatment protocols and ensure the longevity of dental implants, as illustrated in the image below (8).

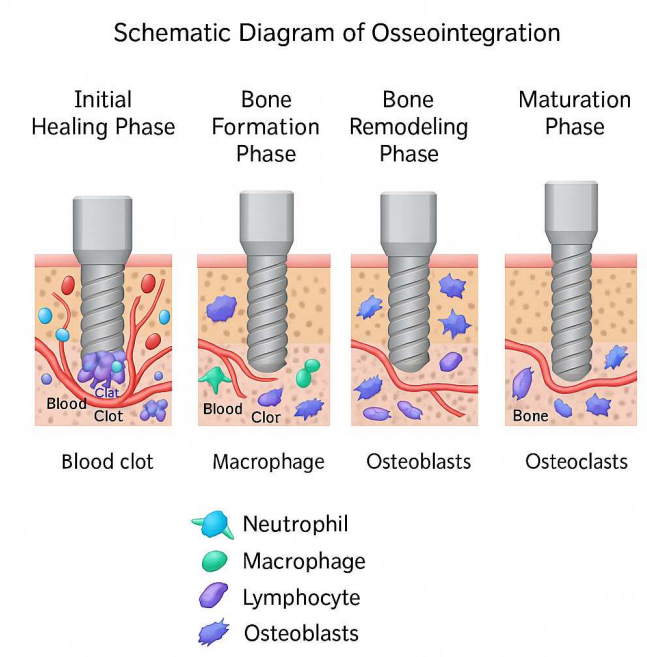

Figure 1 shematic Diagram of osseointegration, Image redrawn and adapted by the author based on: Xiao L. et al., Osteoimmunomodulation role of exosomes derived from inflammatory cells and stem cells in bone regeneration, Frontiers in Bioengineering and Biotechnology, 2022, p. 10.

1.5. Factors Affecting Osseointegration

The success of osseointegration in dental implants is influenced by a combination of factors related to the implant design, surgical technique, and patient-specific conditions.

Implant Surface Characteristics: The surface properties of dental implants, such as roughness, topography, and chemical composition, play a crucial role in osseointegration. Modifications like sandblasting, acid etching, and the application of bioactive coatings can enhance the implant's surface, promoting better bone cell attachment and proliferation (8).

Surgical Technique: The method of implant placement, including the precision of the surgical procedure and the management of the surrounding tissues, significantly affects the healing process and the integration of the implant with the bone. Proper surgical

protocols are essential to minimize trauma and ensure optimal conditions for osseointegration (8).

Patient-Specific Factors: Individual health conditions, such as bone quality and density, systemic diseases (e.g., diabetes), and lifestyle habits (e.g., smoking), can impact the body's ability to integrate the implant. Assessing and managing these factors pre- and post-surgery are vital for the long-term success of the implant (8).

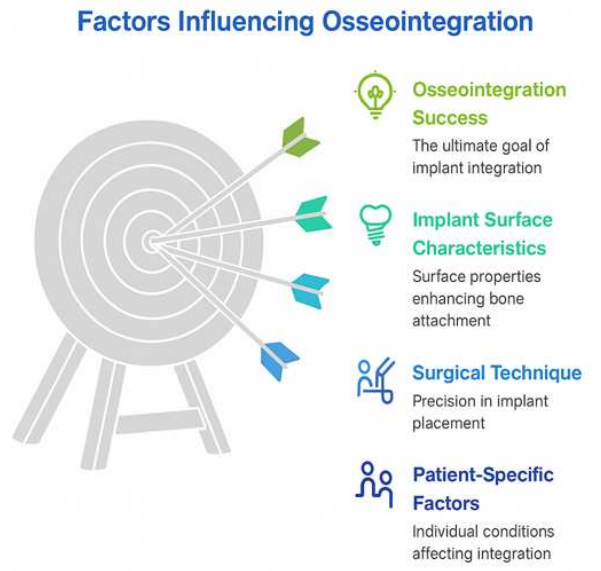

Figure 2 Key Factors Affecting the Success of Osseointegration
Image redrawn and adapted by the author based on: Jeong S-M, Choi B-H. Current knowledge of the factors influencing the success of osseointegration. J Korean Assoc Oral Maxillofac Surg. 2014 Feb;40(2):50–5.

II. Development

1. Anatomical Considerations in Oral Implantology

Understanding Anatomical Structures

The maxilla is a highly vascularized and innervated structure where several arteries and nerves pass in close proximity to potential implant sites. These elements play crucial roles in nourishing the bone and soft tissues, and unintentional injury to them can lead to hemorrhage or sensory complications. An accurate understanding of their position is essential for risk-free surgical planning (9)

1.1. Vascularization and Innervation of the Maxilla

vascularization of Maxilla

The **maxilla** is primarily vascularized by branches of the **maxillary artery**, particularly the **posterior superior alveolar artery**, which enters through the alveolar foramen and distributes blood to the maxillary molars, sinus wall, and associated soft tissues. The **greater palatine artery** emerges through the greater palatine foramen and travels anteriorly along the hard palate. It is consistently located deeper than the **greater palatine nerve**, highlighting the importance of anatomical awareness during surgical procedures involving the palate(10)

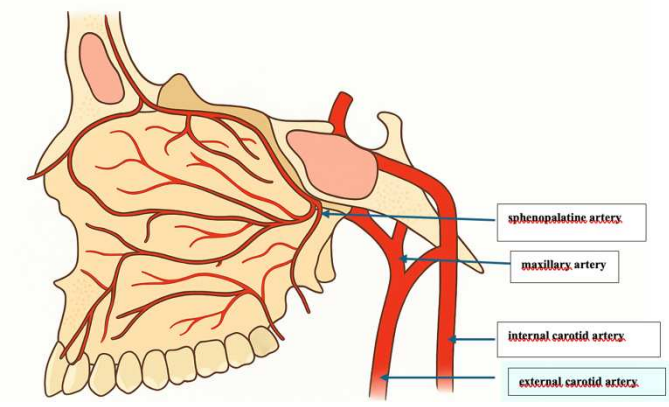

Figure 3 Arterial bleeding in the maxilla

Image redrawn and adapted by the author based on: Louie Al-Faraje, Surgical Complications in Oral Implantology: Etiology, Prevention, and Management, p. 75.

Innervation of maxilla

Innervation is provided by the **maxillary division (V2)** of the trigeminal nerve, which gives rise to the **posterior, middle, and anterior superior alveolar nerves**. These branches supply the maxillary teeth, sinus mucosa, and buccal gingiva. The **greater palatine nerve** courses anteriorly along the hard palate, while the **nasopalatine nerve** traverses the incisive canal to supply the anterior palatal mucosa. Anatomical variations in these nerves may influence anesthesia success and pose a risk for neurosensory complications if not properly identified(11)

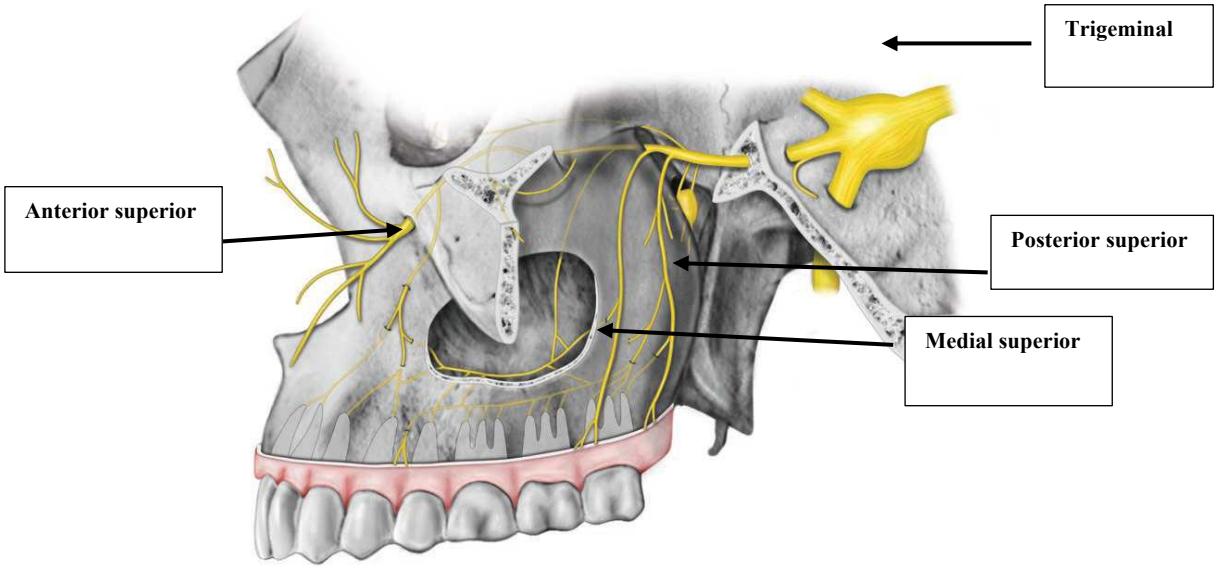

Figure 4 innervation of maxilla, image redrawn and adapted by the author based on: Louie Al-Faraje, Clinical Anatomy for Oral Implantology, 2nd Edition, p. 16.

1.2. Vascularization and Innervation of the Mandible

The mandibular neurovascular system is composed of intricate arterial and neural structures running within or near the mandibular canal and surrounding regions. Because these structures vary in location and dimension, especially in edentulous or atrophic mandibles, their precise identification is critical for avoiding complications such as bleeding or long-term paresthesia (12).

Vascularization of the Mandible

The **mandible** receives its primary blood supply from the **inferior alveolar artery**, which travels through the mandibular canal after entering the mandibular foramen. This artery shows anatomical variation in its origin, sometimes arising from the **middle meningeal artery** or **external carotid artery**, making preoperative imaging essential to avoid complications during implant placement(10)

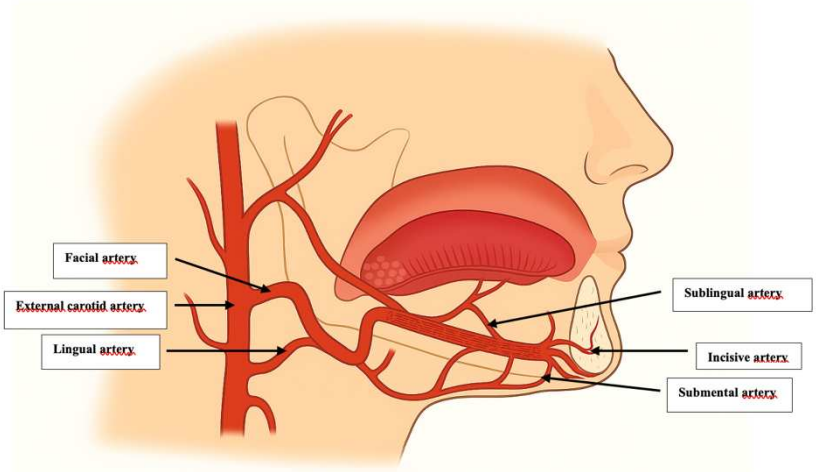

Figure 5 the blood supply of the anterior region of the floor of the mouth,, Image redrawn and adapted by the author based on: Louie Al-Faraje, Surgical Complications in Oral Implantology: Etiology, Prevention, and Management, p. 75.

Innervation of mandible

Neural supply is ensured by the **mandibular division (V3)** of the trigeminal nerve. The **inferior alveolar nerve** follows the same canal as its accompanying artery and provides sensation to the mandibular teeth. The **mental nerve**, its terminal branch, exits the mental foramen to supply the chin and lower lip. The **lingual nerve**, positioned medial to the mandible, innervates the floor of the mouth and lingual gingiva. Variations in the course or branching pattern of these nerves, including anterior looping or bifid canals, are clinically significant and must be carefully assessed prior to surgical intervention(10,11)

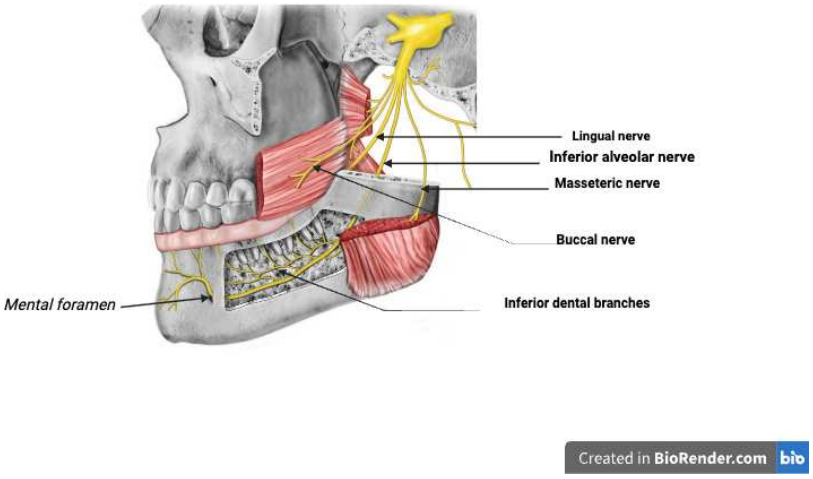

Figure 6 The mandibular nerve.

Image redrawn and adapted by the author based on: Louie Al-Faraje, Clinical Anatomy for Oral Implantology, 2nd Edition, p. 19

2. Classification of Dental Implant Complications

2.1. Classification by Level of Intervention (Modeled on Clavien–Dindo)

Grade I (Minor Deviation):

There exist conditions during postoperative recovery which differ slightly from normal but do not need surgical or pharmacological treatments. The classification system includes small hematomas along with mild bruises and minimal swelling as grade I complications. Research on a large implant group showed a complication rate of 13.9% among 2,400 patients with most problems at this level being minor (Grade I).

Grade II (Medical Intervention Required):

Patients require medication treatment for two purposes: first to fight infections with antibiotics and second to alleviate discomfort with anti-inflammatory drugs. At current stage operations and all invasive interventional procedures become unnecessary.

Grade III (Surgical Reintervention Needed):

The surgical team needs to perform additional surgical procedures because of these important clinical events. The procedure may require draining an abscess and performing surgical correction of implant positioning issues. Several medical establishments divide Grade III procedures into two categories: Grade IIIa uses local anesthetic and Grade IIIb requires general anesthetic .

Grade IV (Life-Threatening):

Implant dentistry presents these problems only rarely but they usually require critical medical care when they occur. Life-threatening complications such as big swelling threatening the breath passage (for instance sublingual hematoma) or the presence of air bubbles (air embolus) require urgent medical intervention (13).

2.2. Classification by Severity

Minor Complications:

Most such complications recover naturally without resulting in permanent harm. A specific example of minor complication is the brief occurrence of pain together with surface-level bruises as research showed their presence in up to 24% of patients (13).

Major Complications:

The injuries affect nerves to produce enduring deficits in neurosensory functions or result in permanent debilitating conditions. The research shows nerve complications from the procedure affect between 0% and 13% of patients (first postoperative evaluations conducted by Bartling et al. identified 8.5% of patients with nerve issues). Mandibular fractures along with severe infections become major complications that affect approximately 0.2% of high-risk implant procedures (13).

2.3.Classification by Preventability

Avoidable Complications:

Patient assessment errors involving inadequate use of 3D imaging (CBCT) become the main cause of these complications when poor implant placement damages vital anatomical structures (such as the mandibular canal).

Unavoidable Complications:

Wearing out protocols during planning does not protect patients from experiencing difficulties due to individual anatomical differences (13).

2.4. Classification by Reversibility

Reversible Complications:

This category includes medical conditions that naturally heal with minimal medical care required. The usual manifestations of this category include short-term sensory disturbances and minor soft tissue swelling that heals within a few days to weeks.

Irreversible Complications:

The permanent damage to the body needs implant removal with possible aggressive surgical corrections. For instance, a permanent deformation of the jaw structures represents an extreme case of mandibular fracture (13)

Summary of Classification of Dental Implant Complications

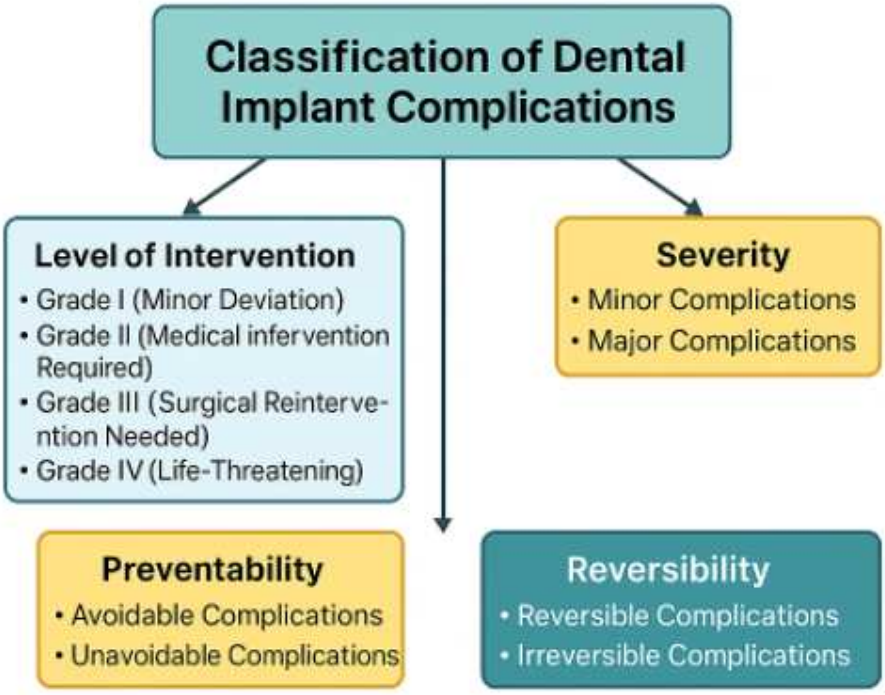

Figure 7 : Classification Criteria of Dental Implant Complications

3. Etiologic Factors for Dental Implant Complications

3.1. Growing Demand and Market Pressures

Misch's text shows implant procedures have become more prevalent because elderly people want better-looking results with improved functionality. The rising patient interest stems from traditional prosthetic dissatisfaction, together with the demand for better treatment approaches. Operating facilities lack uniform planning measures that adjust to the increasing number of implant procedures. Certain practices allow financial incentives and pressure from competition to surpass best practices, which results in minor procedural mistakes and serious complications (14).

3.2. Variation in Practitioner Skills and Training

The clinical care gap among providers who perform implant treatments remains a major influencing factor. The growing market acceptance of implantology among general dentists mainly uses brief ongoing education sessions rather than deep specialist training programs. Their restricted clinical knowledge leads to underestimating detailed anatomical structures and inadequate site developing procedures. The placement of insufficiently planned implants becomes more likely to cause preventable injuries and malposition when healthcare professionals lack full surgical comprehension together with advanced imaging capabilities (14).

3.3. Suboptimal Site Evaluation and Anatomical Challenges

The placement of implants inside compromised or reduced bone tissue leads to most complications, which typically result from extended edentulous periods. The absence of grafting and site development before surgical procedures results in higher possibilities for structural instability, excessive biomechanical stress, and potential damage to fundamental body tissues. Proper identification of the nasopalatine canal and mental foramen, together with the maxillary sinus, helps decrease the risk of hazards during implant surgery(15)

3.4. Patient-Related Medical Factors

Patient-specific systemic conditions also contribute to the complication spectrum. The text outlines that conditions such as uncontrolled diabetes, cardiovascular disease, and the use of certain medications (for example, anticoagulants or bisphosphonates) significantly influence healing and osseointegration. A compromised systemic status can predispose patients to infections, delayed healing, or an unpredictable biological response at the implant site. This aspect underscores the necessity of comprehensive medical evaluation and inter-professional collaboration (such as obtaining proper medical clearance) to reduce the risk of adverse events (14).

3.5. Influence of Patient Medical Background

Misch's research demonstrates that systemic health factors, which include diabetes that lacks control alongside cardiovascular disease and a patient being on anticoagulant medications or receiving bisphosphonate therapy, will affect implant healing times and treatment responses. Patients need a full health review because it provides vital information required to work with their physician in creating specialized treatment plans that minimize both healing complications and infections (14).

3.6. Immediate Placement and Loading Protocols

The text explains that immediate implant placement with subsequent loading provides faster treatment durations along with enhanced patient happiness but required stringent execution guidelines. Implementation of fast surgical approaches must be limited to cases with optimal bone structure whenever surgical execution reaches an exceptional standard. The consequences of choosing inadequate patients or lacking enough experience in immediate loading protocols include both early implant failure and increased neurosensory complications (14).

3.7. Overdependence on Minimally Invasive Methods and "Mini" Implants

The text cautions against the careless application of minimally invasive procedures and small-diameter implants since standard implants would provide better management of functional loads. The installation of "mini" implants reduces perioperative damage, but

such small-diameter implants become prone to fractures and screw loosening, particularly in areas with high biomechanical stress when not planned according to structural needs (14).

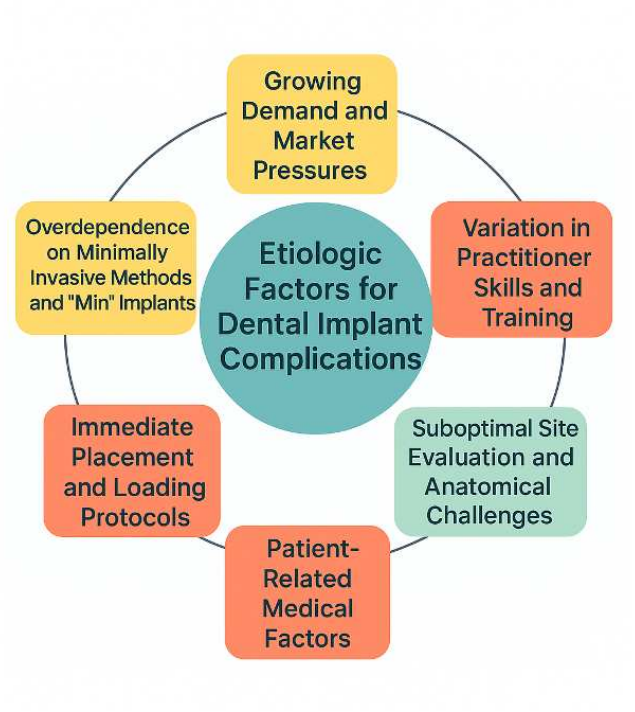

Figure 8: Etiologic Factors Contributing to Dental Implant Complications

4. Intraoperative Complications

Any difficulties in patients undergoing dental implant surgery belong to intraoperative complications. The reliable and safe nature of implant placement often produces adverse outcomes due to unforeseeable issues between anatomical and technical complications, which operators should address beforehand. The potential consequences during surgery include too much bleeding, nerve injury, perforation of the sinus membrane, damage to the surrounding soft tissues, and malpositioned implants (15).

Several treatment-related, skill-related, anatomic knowledge-related, and patient-specific conditions, including bone resorption and anatomical variability, frequently cause these complications. Some surgical complications are easy to handle, but other severe cases lead to sensory difficulties, implant breakage, or postoperative infections.

Understanding intraoperative complications at a deep level, together with proper surgical planning linked to evidence-based protocols, helps reduce morbidity and create better clinical results. The following sections examine surgical complications that regularly occur, along with their subsidiary effects and established methods of avoidance and supervision (15).

4.1. Vascular Complications During Oral Implant Surgery

In recent years, research has highlighted the potential for various vascular complications during oral implant procedures. These complications are divided into soft tissue bleeding, bone bleeding, and major arterial injuries, each of which requires careful management to prevent significant post-operative issues (16).

4.2. Soft Tissue Bleeding

Soft tissue bleeding is reported as the most frequent form of hemorrhage during implant surgery. It results from injury to small submucosal vessels during soft tissue manipulation. Such bleeding often manifests as hematomas or superficial ecchymoses, and it is especially prevalent in older adults, particularly those above the age of 50, due to the physiological fragility of vascular tissues in this group. While generally not life-threatening, these events can be clinically notable and require proper identification to avoid mismanagement. (16).

4.3. Bone Bleeding

Intraosseous bleeding occurs when vascular channels within the bone are disrupted during the preparation of the implant site. This type of hemorrhage is considered a potential complication due to the anatomy of the maxillofacial region, where nutrient canals and blood vessels traverse the alveolar bone. Although typically less severe than major arterial injuries, it is essential to recognize its occurrence, as it may complicate the surgical workflow (16).

4.4. Major Arterial Injury

Although rare, injury to major arteries during implant surgery can lead to substantial blood loss and serious complications. In the maxilla, injuries to the posterior palatine or infraorbital arteries, and in the mandible, to the inferior alveolar artery, are particularly concerning. These arteries supply blood to critical surrounding tissues, and injury can result in heavy bleeding that requires immediate intervention. Preoperative planning using 3D imaging to identify the location of major arteries is vital. Surgical techniques such as careful tissue handling and ligation of injured vessels can effectively manage these risks (16) (17).

4-4-1) Inferior Alveolar Artery

The inferior alveolar artery travels with the mandibular canal and is positioned near the inferior alveolar nerve. In the posterior mandible, notably in conditions where bone height is insufficient, the proximity of the inferior alveolar artery to the cortical surface increases the likelihood of injury during implant procedures. Injury may cause internal bone bleeding and sometimes result in sensory abnormalities, such as paresthesia. (14). (18,19)

4-4-2) Incisive Artery

This terminal extension of the inferior alveolar artery travels toward the anterior midline within the mandibular bone. Implant placement in this region, particularly close to the symphysis, can jeopardize this artery. Complications may include localized bleeding and potential compromise of implant stability due to disruption of local perfusion (19,20).

4-4-3) Sublingual Artery

Branching from the lingual artery, the sublingual artery enters the anterior mandible through the lingual foramen. When the lingual cortical bone is perforated during drilling, it may cause a rapid hematoma under the tongue, which can obstruct the airway and require urgent intervention (4,21)

4-4-4) Lingual Artery

Originating from the external carotid artery, the lingual artery supplies the tongue and floor of the mouth. Although it is not commonly injured, aggressive dissection or deep surgical maneuvers can lead to significant bleeding. Control is often difficult due to the artery's deep location and surrounding tissue pressure. (4,18)

4-4-5) Submental Artery

This vessel, a branch of the facial artery, runs beneath the mylohyoid muscle and is vulnerable during extensive anterior mandibular dissection. If injured, it may bleed into the submandibular space, potentially threatening airway function depending on the extent of swelling. (4,18)

4-4-6) Mylohyoid Arter

A smaller branch arising from the inferior alveolar artery, the mylohyoid artery travels within a shallow groove on the medial aspect of the mandible. It may be inadvertently damaged during posterior flap reflection or graft harvesting, resulting in minor but persistent bleeding.(4)

4-4-7) Buccal Artery

Supplying the buccal mucosa and soft tissues, this branch of the maxillary artery is commonly encountered during flap elevation. Although bleeding from this vessel is typically manageable, careless reflection or trauma in the posterior mandible may trigger unexpected soft tissue hemorrhage. (4)(Misch & Resnik, 2017).

4-4-8) Facial Artery

Crossing over the mandible near the antegonial notch, the facial artery is susceptible during aggressive surgical retraction or when flaps are designed without accounting for its location. If compromised, it can cause visible swelling and bleeding along the cheek or lower face. (4,18)

4.5. Hematoma Formation in the Floor of the Mouth:

This area is particularly prone to hemorrhage due to its dense vascular supply, especially the sublingual artery. Injuries in this region can lead to hematomas, which may cause discomfort, swelling, and, in extreme cases, airway obstruction. In some instances, surgical drainage may be necessary to alleviate pressure. To minimize risks, meticulous surgical techniques and intraoperative imaging are crucial for avoiding trauma to the blood vessels in this sensitive area (16).

Figure 9 Sublingual hematoma leading to an elevated and retruded tongue, Adapted from Barrientos-Lezcano et al., 2021. Reproduced with permission under Creative Commons license (CC BY-NC-SA 4.0) (54).

5. Nerve Complications in Oral Surgery and Implantology

The management of nerve injuries during oral implantology, such as mandibular paresthesia, requires prompt diagnosis and appropriate intervention to restore nerve function and prevent long-term sensory deficits. Careful surgical planning, accurate imaging, and timely clinical management play a crucial role in minimizing such complications (22).

5.1. Symptoms of Nerve Injury

Nerve injuries manifest as numbness, paresthesia, dysesthesia, or pain in the affected area. These symptoms can be temporary or permanent depending on the severity of the injury.

Neuroma formation following nerve trauma may exacerbate neuropathic pain, particularly near surgical site (23).

5.2. Types of nerve injury and classification of nerve injury in implant dentistry.

In dental implant operations, nerve trauma can cause various forms of sensory change. These include (24)

Paresthesia, where the patient gets abnormal sensations like tingling or numbness and it may even be without stimulation at all.

An unpleasant or painful response to either normal or abnormal stimulation is known as **dysesthesia**.

Analgesia is a lack of perception of pain.

Anesthesia is the complete loss of any type of sensation, touch, or temperature.

6. Classifications of Nerve Injuries

To classify the level of damage to nerves, we use the widely accepted **Seddon classification system:**

Neurapraxia is a temporary loss of nervous function without structural interruption. It usually comes on its own with time.

Axonotmesis is the case when the internal fibrous substance of the nerve is not damaged but only the enveloping nerve sheath remains intact. It is possible to recover albeit it will take longer.

Neurotmesis is the most severe type, in which the nerve is completely cut off, very frequently calling for a surgical intervention because there is no natural recovery possible (24).

6.1. Injury Caused by Anesthesia

Intraoperative complications in implant dentistry can include nerve disturbances linked to anesthesia. Specifically, inferior alveolar nerve blocks may result in altered sensations such as paresthesia or anesthesia. These effects are associated with the technique used, particularly when targeting the mandibular or lingual nerve regions. The article emphasizes that these changes are often temporary, but may vary depending on the extent and location of the affected nerve.(15).

6.2. Injury Caused by Nerve Compression

Sensory impairments can also result from mechanical interference during surgery. When a drill or implant is placed too close to the mandibular canal, it can provoke hematoma formation that compresses the inferior alveolar nerve. This pressure may cause symptoms such as numbness or paresthesia in the chin or lip, especially if the canal is perforated or if anatomical variants such as accessory canals are involved. (15).

6.3. Injury Caused by Surgical Procedures

Surgical trauma to nerves during oral implantology is a common complication caused by drilling, flap elevation, or improper instrument handling. The lingual nerve and inferior alveolar nerve are particularly vulnerable during mandibular surgeries. Factors such as over-aggressive drilling, improper flap design, or lack of precision near critical anatomical structures can increase the likelihood of nerve damage.(25)

6.3.1. Mental Nerve

The mental nerve, a branch of the inferior alveolar nerve, exits through the mental foramen and innervates the lower lip and chin. Injury during implant placement in the premolar region or soft tissue manipulation can lead to sensory disturbances. Careful planning and identification of the mental foramen are critical(23)

6.3.2. Inferior Alveolar Nerve

This nerve, running within the mandibular canal, is highly vulnerable during implant placement in the posterior mandible. Injury causes significant sensory loss or pain in the mandibular teeth and lower lip. Proper depth control during drilling and implant placement helps prevent damage(15).

6.3.3. Mandibular Incisive Canal and Nerve

The mandibular incisive nerve, a continuation of the inferior alveolar nerve, supplies anterior teeth. Its damage can result in paresthesia or loss of sensation in the anterior mandibular region. CBCT imaging assists in assessing the nerve's pathway to avoid complications (23).

6.3.4. Lingual Nerve

The lingual nerve, located close to the third molar region, is prone to injury during flap elevation or drilling. Damage may lead to sensory disturbances in the tongue, such as numbness, altered taste, or pain. Avoiding deep incisions and careful soft tissue handling reduces risks (15).

6.3.5. Infraorbital Nerve

The infraorbital nerve, emerging from the infraorbital foramen, innervates the maxillary anterior teeth and surrounding soft tissues. Damage during sinus lift or anterior maxillary implant placement may cause numbness in the midface and upper lip. Identifying the nerve's location preoperatively with imaging is essential (23).

7. Infections in the Intraoperative Phase of Implant Surgery

Intraoperative infections, though not so common in implant dentistry, can lead to worst-case scenarios in wound healing and implants over the long term. Such complications are mostly due to a number of intraoperative factors. When there is a breach of aseptic technique, such as a suboptimal sterilization of instruments, a lack of appropriate handling of surgical materials, and a failure to maintain a sterile field, among others, this is still the main culprit. As mentioned by Misch (2008), poor irrigation while preparing the osteotomy may lead to localized bone necrosis involving the formation of a nidus for bacterial colonization. In addition, excessive tissue manipulation, long surgical times, and wrong usages of barrier membranes could further aggravate infection risk (4).

In addition, Bagheri et al. (2021) note that grafted materials that are contaminated or past their expiration date, gloves being contaminated by coming into contact with non-sterile surfaces before grafting, and accidental introduction by aerosol or saliva exposure of oral flora are also common forms. The existence of such uncaught chronic infections like residual cysts, periapical lesions, or periodontally-compromised adjacent teeth that exist within the surgical area can be brought back to active by the surgery if not previously handled. Besides, there will be inadequate hemostasis in the event that a hematoma is possible, which acts as a medium for microbial growth.

Such factors undermine the sterile environment that is necessary for implant integration and may result in implant failure early, peri-implantitis, or delayed healing (3)

8. Complications Related to Surgical Technique in Oral Implantology

8.1. Flap Design Errors

Intraoperative complications related to flap design during implant surgery usually find their origin in poor planning or execution, and have an immediate bearing on visibility, vascular supply, and soft tissue management. A wrong choice of flap, either too generous or insufficient, can cause excess bone exposure, more trauma, or lack of blood supply, which could influence the primary stability if not affecting the healing of the wound. The recent literature (Singh et al., 2023) states that the optimum flap design should take into account the implant location, anatomical structures, and the need for grafting.

Employment of full-thickness or partial-thickness flaps has to be based upon individual clinical needs so as to prevent unnecessary manipulation or tension. Moreover, the failure to comply with surgical principles already accepted – e.g., providing sufficient access, not damaging periosteum, not putting excessive stretching on its components – may lead to unintended damage to tissues. (26).

8.2. Thermal Bone Damage

Excessive trauma to bone tissue by intra-operative heat raises a real issue during implant site preparation, since the excess can cause osteonecrosis, disrupting osseointegration. Recent research has shown that conventional sequential drilling protocols can accidentally lead to major temperature increases, where the initial drills cause the highest temperatures that are over 100 ° C. This heat can travel several millimeters out of the osteotomy site, and corresponding drilling steps may not be sufficient in reducing the first thermal insult. Attributes such as the drill design, rotational speed, and applied pressure play critical roles in heat generation. Hence, in optimizing these parameters, we need to minimize thermal injuries and have favorable implant integration outcomes (27).

8.3. Implant Mispositioning

Insufficient planning and absence of surgical conduct lead very commonly to intraoperative mispositioning of implants, as shown in the clinical case presented by Tallarico et al. (2020). In surgery, the implantation occurred without a guided system but using a free-hand technique. This resulted in mal-relationship in bucco-lingual directions and a lack of proper orientation in planes, culminating in phonetic issues, maintenance of hygiene, and the presence of several prosthetic issues later. There was a severe violation of the prosthetic space; one implant was so buccally placed, which led to the thread exposure, increasing the biological risk. The authors insisted that such mistakes made on the spot during inserting implants could have been avoided if digital planning tools and surgical guides were used. Their case depicts how intraoperative choices that are not compliant with prosthetic and anatomical considerations may result in aesthetic failure and mechanical breakdown, even if the implant itself is osseointegrated (28).

8.4. Aspiration or Ingestion of Foreign Objects

Intra-operative aspiration of dental instruments during an implant procedure is a rare and serious complication that is of great urgency. Gandagule et al. (2025) published a case of a 67-year-old male who accidentally inhaled an implant driver in the process of mandibular implant placement. Even though there was no immediate symptom of coughing or choking, the radiographic evaluations, such as the thoracic and spinal X-ray, followed by a computed tomography scan, confirmed that the implant driver was in the right main bronchus. A successful removal of the foreign body was made by rigid fibre-optic bronchoscopy under general anesthesia. Postoperative care entailed monitoring in the intensive care unit with nebulization, antibiotics, and corticosteroids to avoid complications. This situation highlights the necessity of urgent diagnosis and intervention in the case of such emergencies (29).

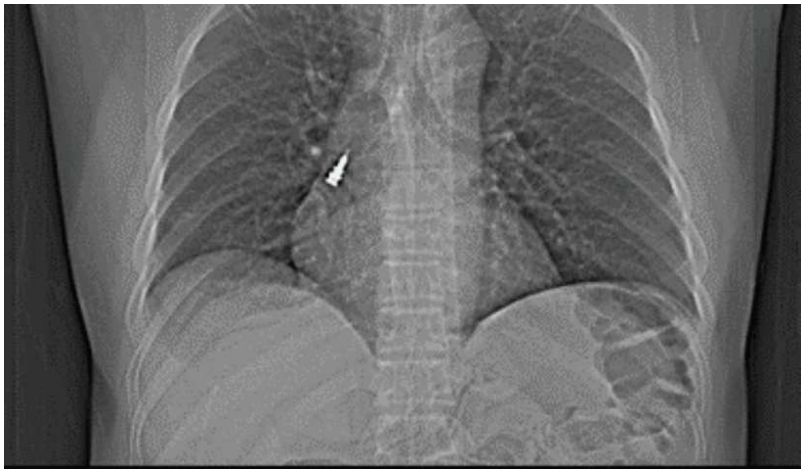

Figure 10 : Chest X-ray confirming the presence of an implant driver in the right bronchus. Adapted from Gandagule et al., 2025. Reproduced with permission under Creative Commons license (CC BY 4.0) (55).

8.5. Injury to Adjacent Teeth

Tooth damage around the implant site is a known intraoperative complication; it is frequently associated with incorrect implant location/ incorrect angulation. In a long-term retrospective analysis, Yi et al. (2021) divided such injuries into three separate types. Direct penetration of the root structure, surface contamination of the root, and instances whereby an implant had been placed within 1 mm of a root of a neighboring tooth. During a follow-up duration that exceeded ten years, the study noted that a subset of affected teeth needed endodontic intervention, followed by a smaller fraction that was salvaged. However, all the injured teeth were functional, with a survival rate of more than 90%. These findings underscore the necessity to keep a distance between implants and nearby roots in order to minimize the risks of biologic and functional complications. (30).

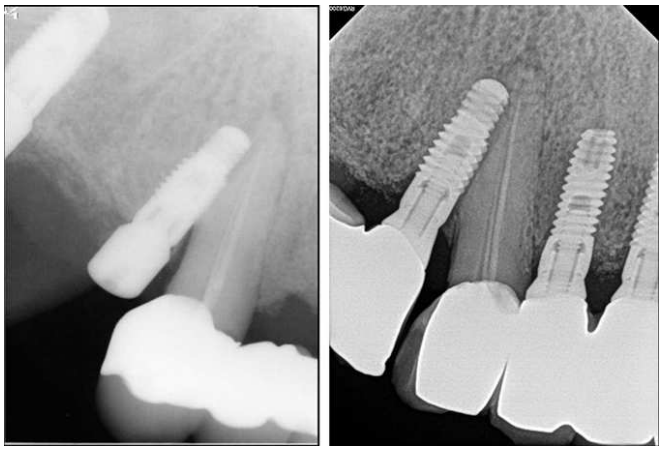

Figure 11: Direct invasion of the endodontically treated adjacent tooth by a dental implant. (Left) At the time of implant surgery, June 2012; (Right) at 8 years after injury, August 2020.
Adapted from Yi et al., 2021. Reproduced with permission under Creative Commons license (CC BY 4.0) (56).

8.6. Inadequate Initial Stability

It is important to achieve primary stability during the process of dental implant placement, which is a vital parameter for attaining a successful osseointegration and long-term success of the implant. Poor initial stability, which is frequently caused by the lack of good bone quality, lack of enough bone volume, or insufficient surgical technique, may compromise the healing process and initiate implant failure. Javed & Ahmed (2013) indicate that the primary stability is influenced by bone density, implant design, and

surgical protocol. They point out the fact that implants that go into low-density bone, for instance, the posterior maxilla, are at a higher risk of having an insufficient degree of stability (31).

8.7. Mandibular Bone Fracture

Mandibular bone fracture represents a rare but very severe intraoperative complication that may occur during implant placement, particularly in patients with compromised bone conditions. This complication may occur even in patients who do not have evident medical risk factors, especially if four implants are inserted at once into the anterior mandible. Mechanical stress from the procedure of the insertion of implants, coupled with undiagnosed systemic conditions like decreased level of bone mineral density, can cause weakening of the mandible and fracture. Some clinical signs that may present during or after the operation include acute pain and mandible mobility, as well as soft tissue bleeding. The present case illustrates the necessity of pre-surgical evaluation of bone quality, including radiological examination and systemic evaluation of bone health, in order to prevent mechanical overload while placing implants. When working in areas of suspected bone fragility, preventive measures such as staging the surgeries or alteration of implant distribution and length are important (32).

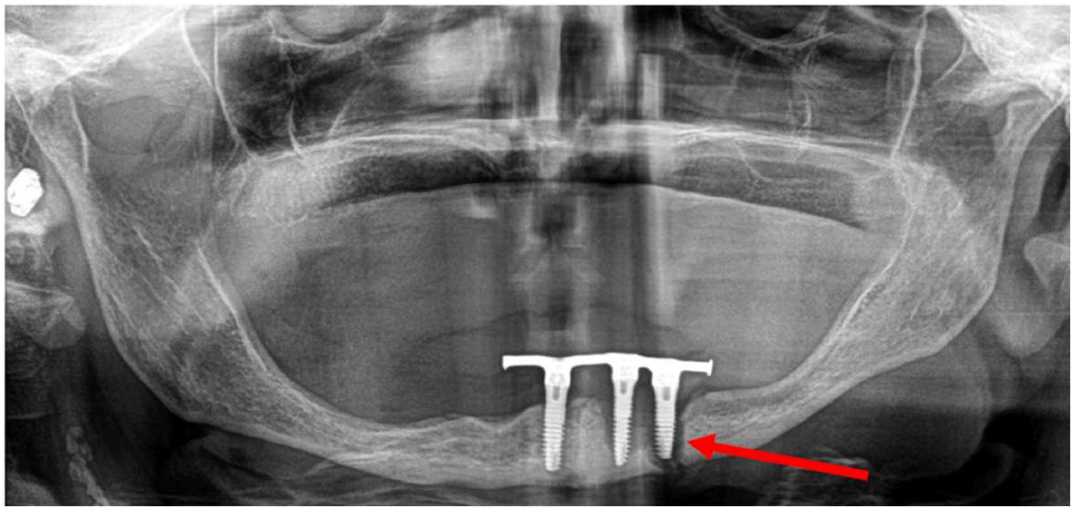

Figure 12*:* image showing a left mandibular parasymphysis fracture secondary to peri-implantitis. The red arrow indicates the fracture site. Adapted from Benito Anguita et al., 2024. Reproduced under Creative Commons license (CC BY 4.0) (57).

8.8. Accidental Displacement into the Maxillary Sinus.

There is a certain danger of an implant being accidentally pushed into the maxillary sinus during the placement of implants in the retromaxilla. This intraoperative complication is likely to occur where the remaining alveolar ridge is thin or close to the implant location to the sinus floor. According to An et al. (2017), inadequate bone strength and overpowering insertion pressure relative to drilling or implant installation may lead to the breach of the sinus floor. Imprecision or poor determination of sinus structures adds to such an occurrence. With the implant not firmly held in place by the pressure exerted apically, the implant may migrate beyond the desired treatment area, getting into the sinus cavity during the actual surgical procedure itself (33).

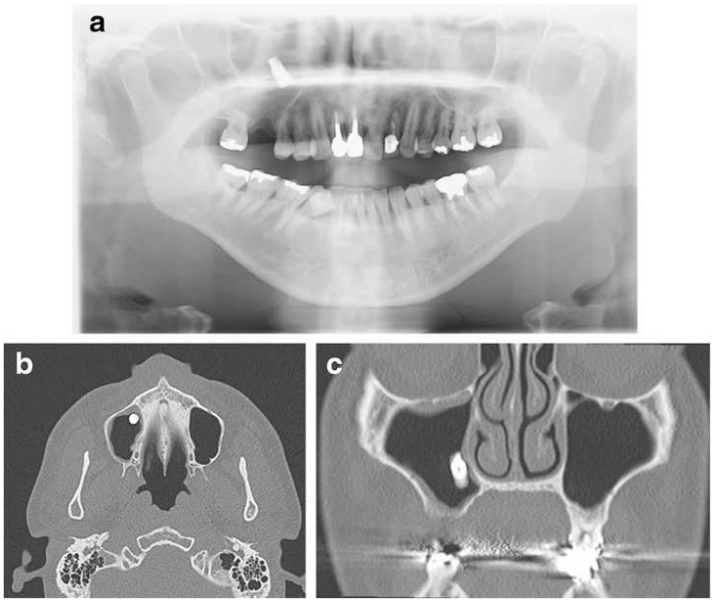

Figure 13 :(a) Panoramic radiograph showing implant displacement into the maxillary sinus; (b) axial CT scan and (c) coronal CT scan obtained preoperatively. Adapted from Nogami et al., 2016. Reproduced under Creative Commons license (CC BY 4.0) (58).

8.9. Maxillary Sinus Floor Perforation

Sinus floor perforation, especially the Schneiderian membrane, is a known risk in implant procedures in the posterior maxilla. This complication occurs normally in a sinus elevation procedure where there is insufficient vertical bone height to hold the implant. Anatomical problems like the thinness of a sinus membrane or the existence of sinus septa can contribute to the increased risk of the membrane tearing. Beck-Broichsitter et al. (2020) state that the risk of perforation grows as the procedure becomes technically

inaccurate, if much force is used, or if the visualization of the membrane elevation is not good. Such perforations, as a rule, remain unnoticed at once, but may spoil the surgical field, undermine implants' stability, and impede the healing (34).

8.10. Nasal Floor Perforation

While conducting the implant placement procedure in the anterior maxilla, one important intraoperative complication is the unintended damage to the nasal floor. This risk is increased especially in severe cases of alveolar bone loss, where there is only a little height of residual bone between the ridge and the nasal cavity. Failing to have an accurate three-dimensional assessment, clinicians risk over-penetration of the nasal floor when they are drilling, especially in regions with high anatomical risk. Park et al. (2023) indicate that such perforations are usually associated with misappraisal of existing bone height or trajectory during surgery, particularly when using 2-D imaging only. The existence of the thin cortical bone at the base of the nasal improves the chances of this complication during the preparation of osteotomy (35).

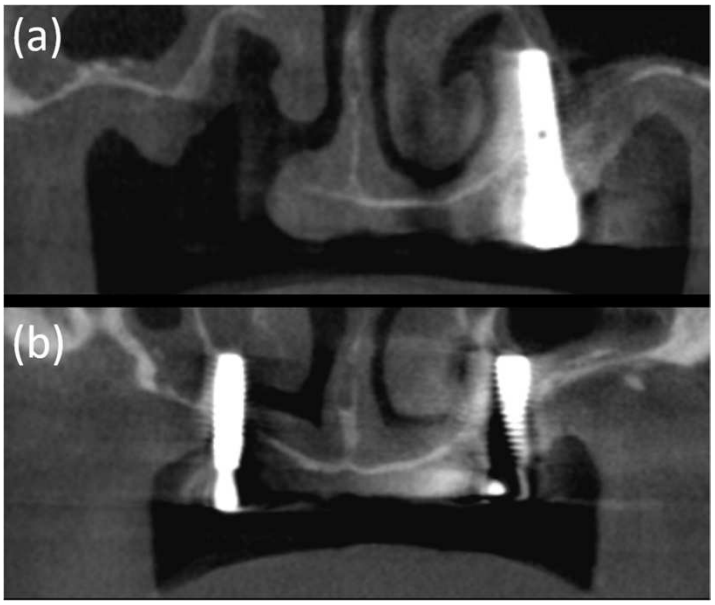

Figure 14 : CBCT images of case 2 patient. An obvious discontinuity of the inferolateral cortex of the nasal cavity and oronasal fistula is observed due to explantation (a). The residual fixtures on both sides of the maxilla perforated the nasal cavity and are placed just medial to the maxillary sinus (a, b).
Adapted from Yeom et al., 2023. Reproduced under Creative Commons license (CC BY 4.0) (59).

9. Prevention and Management of Intraoperative Complications:

9.1. Soft Tissue Bleeding

Prevention

To minimize the risk of soft tissue bleeding during oral surgery, careful flap design, minimal trauma during tissue manipulation, and appropriate suturing techniques are essential. In patients on anticoagulant therapy, verifying that therapeutic levels are within a safe range before surgery is a key preventive strategy(36,37) .

Management

Initial bleeding is typically managed through direct pressure using sterile gauze. If this is insufficient, additional steps may include resuturing the wound or applying topical hemostatic agents to support clot formation. In cases where bleeding is persistent or more severe, measures such as vessel cauterization or the use of advanced local techniques may be required to achieve effective hemostasis (36,37).

9.2. Bone Bleeding

Prevention

Proper planning using CBCT and conservative drilling methods is a measure of avoiding bone vessel's damage. There is less periosteal trauma with the flapless or the minimally invasive method (36,37).

Management

Bone bleeding is commonly addressed by inserting the implant into the prepared site, which contributes to controlling the bleeding by occupying the space. If this measure does not achieve sufficient hemostasis, additional tools such as absorbable hemostatic sponges or bone wax can be used to promote clotting. Proper suturing techniques are also important, as they help maintain tissue position and provide stability to the area, reducing the chance of renewed bleeding during the early healing phase (36,37).

9.3. Lingual Artery

Prevention

To reduce the risk of lingual artery injury during implant surgery, it is essential to avoid deep penetration of the lingual cortical plate and excessive instrumentation in the floor of the mouth. Preoperative imaging using CBCT aids in identifying anatomical variations and helps ensure proper angulation during (4, 13)

Management

Initial management includes applying local pressure and, if needed, gently pulling the tongue forward to assist access. Monitoring the airway is essential due to the risk of floor of mouth hematoma. In cases of ongoing or severe bleeding, surgical measures such as vessel ligation or embolization may be required to stop the hemorrhage (4,13).

9.4. Submental Artery

Prevention

Pre-surgical imaging aids in estimating the bone height and prevent deep lingual drilling especially in resorbed mandibles. Positioning should not go below the lower mandibular border.

Management

In the event of submental artery injury, firm bimanual compression should be applied simultaneously to the submental region externally and the floor of the mouth internally. This helps control initial bleeding and limit hematoma expansion. If the swelling continues to increase, particularly in the floor of the mouth, it can compromise the airway. In such cases, prompt airway protection is crucial. When bleeding does not resolve with pressure, surgical access to identify and control the bleeding vessel may be required (4) (13)

9.5. Mylohyoid Artery

Prevention

Use caution when raising the flaps of lingual, and do not be tempted to use rough handling close to the mylohyoid groove. The use of piezosurgical tools leads to minimization of soft tissue trauma (10,13).

Management

Bleeding from the mylohyoid artery, when limited, can generally be managed with the application of direct pressure at the site. If necessary, bone wax may be placed over the bleeding point to assist in sealing the vessel. In situations where local measures are insufficient and bleeding continues, controlled use of electrocautery provides an effective method to stop the hemorrhage while minimizing further trauma to the surrounding tissues (10,13)

9.6. Buccal Artery

Prevention

To reduce the risk of buccal artery injury during surgical access, it is important to avoid making excessively deep or wide incisions in the posterior vestibular region. Gentle flap reflection is recommended to prevent unnecessary trauma to the soft tissues and underlying vessels (4).

Management

Bleeding from the buccal artery is typically minor and can often be controlled by applying firm, localized pressure. If hemostasis is not achieved with pressure alone, the use of suture ligation can help isolate and close the bleeding vessel. Alternatively, electrocautery may be applied to coagulate the source and stop the hemorrhage effectively(4).

9.7. Facial Artery

Prevention

Surgical access near the mandibular notch should be avoided to reduce the risk of facial artery damage. Additionally, manipulation of soft tissues in this region must be performed with caution to prevent vascular injury (4,18).

Management

If bleeding occurs, applying external pressure along the jawline may help control it. Should the bleeding continue, surgical ligation of the vessel may be required. When hemorrhage cannot be effectively managed, prompt referral to a hospital setting is indicated for further treatment (4,18).

9.8. Hematoma in the Floor of the Mouth

Prevention

To reduce the risk of hematoma formation in the mouth floor, guided drilling should be used instead of blind techniques. When working in areas with higher vascular risk, flap elevation should be considered. CBCT imaging assists in visualizing the vascular anatomy and planning the approach accordingly (16,21).

Management

When a hematoma forms in the floor of the mouth, immediate and coordinated action is critical due to the potential for airway compromise. The first step involves applying firm bimanual pressure externally on the submental region and internally on the mouth floor to control bleeding and limit the spread of the hematoma.

Simultaneously, the airway must be closely monitored, as the expansion of the hematoma in this confined anatomical space can rapidly displace the tongue upward and backward, obstructing the airway. In both sources, cases have shown that airway obstruction can occur within minutes, highlighting the need for fast recognition and response.

If the swelling progresses or does not respond to pressure, **emergency medical care** is necessary. At this stage, **surgical intervention**, such as incision and drainage, may be

required to evacuate the hematoma and relieve pressure. In some reports, securing the airway via intubation or tracheostomy has been necessary when respiratory compromise was imminent or already presen.(16,21)

Summary of Vascular Complications

Table 1 :Summary of Vascular Complications in Oral Implant Surgery – Prevention and Management Strategies

Complication	Prevention	Management
Soft Tissue Bleeding	Careful flap design, minimal trauma, appropriate suturing; ensure safe anticoagulant levels (16).	Direct pressure with gauze; resuturing, hemostatic agents, or cauterization if needed(16).
Bone Bleeding	Use CBCT, conservative drilling, and flapless techniques(16).	Implant placement to compress site; use sponges, bone wax, sutures if needed(16).
Lingual Artery	Avoid deep drilling in lingual cortex; use CBCT for planning (4,18).	Apply pressure, pull tongue forward, monitor airway, surgical intervention if needed (4,18).
Submental Artery	Estimate bone height preoperatively, avoid drilling below mandibular border (4,21).	Bimanual compression; secure airway; surgical control if bleeding persists. (4,21)
Mylohyoid Artery	Gentle flap handling near mylohyoid groove; use piezosurgery. (4)	Apply pressure; use bone wax or electrocautery if bleeding continues. (4)

Buccal Artery	Avoid deep incisions in posterior vestibule; gentle flap elevation. (4).	Apply pressure; use suture ligation or electrocautery if needed. (4).
Facial Artery	Avoid mandibular notch area; gentle soft tissue manipulation. (4,18)	Jawline massage; surgical ligation if bleeding persists; refer to hospital if severe. (4,18)
Hematoma (Floor of Mouth)	Use guided drilling, elevate flaps in high-risk areas; assess vascular anatomy via CBCT. (16)	Bimanual pressure, airway monitoring, surgical drainage, emergency care if airway compromised. (16).

10. Nerve Injuries Prevention and Management

10.1. Injury Caused by Anesthesia

Prevention

To minimize the risk of nerve injuries during local anesthetic procedures, it is crucial to employ meticulous techniques. This includes careful needle placement to avoid direct trauma to nerves, particularly the inferior alveolar and lingual nerves. Utilizing appropriate injection techniques and being aware of anatomical variations can further reduce the likelihood of nerve damage(38) .

Management

In instances where nerve injury occurs, prompt recognition is essential. Patients should be monitored for signs of altered sensation or pain following anesthesia administration. If symptoms persist, referral to a specialist for further evaluation and management is recommended. Treatment options may include pharmacological interventions or, in some cases, surgical exploration, depending on the severity and duration of the symptoms (38).

10.2. Injury Caused by Nerve Compression

Prevention

Try to decrease the tightness and movement of the flaps while performing the surgery. Make sure not to apply strong and prolonged pressure that can damage nerve tissue (23).

Management

Hurrying with the decompression can minimize nerve-related complications after surgery. If the numbness or pain remains even after taking care of the pressure, continuous observation is needed. Some forms of supportive care are analgesics, corticosteroids, and physical therapy to help the nerves heal. Surgical decompression might be necessary if other treatments do not work or the symptoms get worse even after several months (23).

10.3. Mental Nerve

Prevention

Take radiographs to make sure you find the mental foramen. Avoid over-pulling and deep-cutting the tissue in this spot (15) .

Management

In most cases, mild mental nerve dysfunction goes away on its own. If pain persists or is quite severe, anti-inflammatory tablets, vitamin B complex, or medications for neuropathic pain may be used. When a suspected implant impingement is found, an X-ray must be done, and possible solutions involve adjusting or removing the implant. If the problem continues, a referral to surgery or decompression may be needed (23).

10.4. Inferior Alveolar Nerve

Prevention

Attaching depth stoppers and performing CBCT imaging before surgery helps to avoid the location of the mandibular canal (15).

Management

Numbness in the lips or chin can be caused when a nerve gets pressed or trapped. For this reason, it is best to seek help early. The pressure can be relieved on the eye by either removing or repositioning the implant. If the symptoms have not resolved, imaging and nerve tests may be suggested for further management. Tissues can be treated with anti-inflammatory drugs, and if the problem is not resolved, specialists may refer patients for surgery or repair of the affected nerve (23)

10.5. Mandibular Incisive Canal and Nerve

Prevention

To reduce the risk of damaging the mandibular incisive nerve, preoperative imaging is recommended to identify the position and course of the anterior canal. Particular caution should be taken to avoid drilling too deep in this area, as its proximity to vital nerve structures can increase the likelihood of injury(15)

Management

Most injuries involving the mandibular incisive nerve tend to be mild and temporary. These cases generally improve over time without requiring specific intervention. Regular observation is usually sufficient to assess recovery. According to available clinical data, active treatment is rarely necessary, and spontaneous resolution is often expected unless symptoms persist beyond the typical healing period(23).

10.6. Lingual Nerve

Prevention

Make sure not to perform incisions or deep dissection in the area of the molars. Elevating the tissue just below the bone, as in subperiosteal ways, leads to less risk(25).

Management

Timely intervention is crucial. If there is paresthesia or dysesthesia in the tongue, having surgery within a three-month period provides the best opportunities to recover sensation. Possible surgeries are nerve repair, grafting, or the removal of a neuroma. Neurotrophic

support and desensitization therapy may be a part of the long-term rehabilitation process (25) .

10.7. Infraorbital Nerve

Prevention

Because of just how close the infraorbital foramen is to the maxillary sinus, consider doing CBCT to properly locate it and avoid setting implants in closest proximity (15).

Management

Monitor for spontaneous recovery. If someone continues to experience persistent back pain for 6-12 weeks, it may be useful to consider decompression surgery (23).

Summary of Nerve Complications

Table 2 :Summary of Nerve Complications

Complication	Prevention	Management
Injury by Anesthesia	Gentle technique near foramina; aspirate before injection. (38) .	Immediate observation; refer to neurologist or surgery if persistent. (38) .
Nerve Compression	Avoid tight flaps and excessive pressure. (23).	Early decompression; monitor; surgical release if symptoms persist. (23).
Mental Nerve	Identify foramen radiographically; avoid excessive retraction. (15) .	Monitor; consider medications; adjust or remove implant if impinging. (23).

Inferior Alveolar Nerve	Use CBCT and depth stoppers. (15)	Early detection, implant adjustment; anti-inflammatory treatment; surgery if needed. (15)
Mandibular Incisive Nerve	Avoid deep drilling; use imaging. (15)	Most recover without intervention; monitor. (23)
Lingual Nerve	Avoid deep incisions in molar area; subperiosteal technique preferred. (25)	Surgery within 3 months if needed; nerve repair, grafting, therapy. (25)
Infraorbital Nerve	Use CBCT to localize infraorbital foramen. (15)	Monitor; decompression if no improvement after 6–12 weeks. (23)

11. Prevetion and management of other intraoperative complications

11.1. Infections that Develop During the Surgery

Prevention:

Often, infections during implant surgery result from not following the agreed-upon surgical protocol. To prevent this problem, surgeons need to keep the area around the patient clean and disinfect all the instruments and materials used. Overhandling soft tissues, surgery that lasts too long, and not rinsing well during drilling may cause more bacteria to be introduced. If the temperature during drilling is not maintained at the proper level, local bone injuries can occur, making the area easy for microbes to develop. Before an implant is placed, any oral infections that may be present, such as cysts or aftereffects of previous disease, should be handled to prevent contaminating the surgical area (3).

Management:

Should the team notice blood that is oddly abundant, pus or changes in the surrounding tissues, they must react right away. The area needs to be thoroughly watered and any contaminants such as grafts or membranes, should be taken out. Achieving hemostasis helps block the formation of hematomas, as they can harbor bacteria. If removal of the infection is required before the implant can succeed, it may be wise to hold off on the procedure for a while and modify the surgical strategy once everything is under control.(3)

11.2. Errors in the Flap Design

Prevention:

An appropriate choice of flap is necessary to prevent difficulties during implant surgery. Where the implant is to be placed, if there are important structures nearby, and whether a graft of bone will be required are important points to review before deciding on a full-thickness or partial-thickness flap. When the flap is planned correctly, it helps ensure the area is easily reached, seen, and protected, which is necessary for recovery. Avoiding overly stretching or insufficiently extending the flap helps prevent further injury and damage to the soft tissues (39).

Management:

Sometimes, if the designer of the flap is not up to standard, the surgeon can attempt to improve it by stretching the flap wider or easing up strong tension. The disruption of soft tissue and the periosteum should be as minimal as possible. If more than the required amount of skin is damaged or exposed, care should be taken to sew the wound taut but gently enough and to treat it post-surgery as infection or flap loss must be avoided (39).

11.3. Thermal Bone Damage

Prevention:

During implant drilling, heat damage to the bone can disturb the process of implant integration. The initial parts of drilling usually result in the greatest rise in temperature, and this increase might move far from the osteotomy. Drill geometry, how fast it rotates,

and pressure are all factors that affect heat directly. Maintaining the right environmental conditions with the proper irrigation decreases the risk of overheating and aids successful farming (27).

Management:

If it is suspected that a bone is overheated during the surgery, bringing down its temperature right away is important. If the bone is overheated, it may not securely hold the implant, and inserting the implant could impact future results. Sometimes, the procedure must be postponed, or another site must be chosen due to severe damage (27).

11.4. Mispositioned implants

Prevention:

Surgeons may misplace the implants during surgery if they use free-hand methods and fail to plan well. Without accurate surgical reference, placing implants might lead to deviations of the device's location in or outward from the teeth. They may lead to breakage in the prosthesis or hurt the body tissue management process. Reliable results require the proper use of digital planning and surgical guides, so complications are avoided during and following surgery (28).

Management:

If implants are put in the wrong positions during surgery, the next actions depend on whether the problem is significant or not. If the thread in the gum tissue becomes visible, this may cause the nearby gums to break down and become inflamed. In some cases, injured areas can be improved using prosthetics or grafting materials to achieve a natural appearance. Should movement not be a choice, the part will likely need to be removed and installed again when a suitable moment arises. To be healthy in the future, it is important to spot problems early and give appropriate treatment through prosthetics or surgery (28).

11.5. Aspiration or Ingestion of dental instruments

Prevention:

Aspiration of a dental instrument during implant surgery is not common, but it can be a major risk during surgery. Guaranteeing a clean worksite and careful handling of all tools may help prevent such accidents. To prevent injury, you should use throat gauze screens, fit safety ligatures to very small instruments, and arrange patients carefully before any minor surgery in the mandible area. They prevent things from being swallowed accidentally into the throat or lungs (29).

Management:

Even if no symptoms are shown, suspecting a foreign object in the lungs requires health workers to immediately check the X-rays to verify. Pictures of the chest and CT scans help the surgeons identify the object. In cases that have been confirmed, taking out the foreign object under general anesthesia during bronchoscopy is the recommended option. To stop more respiratory problems, patients undergoing surgery should receive intensive care and treatments such as nebulization, corticosteroids, and antibiotics (29).

11.6. Injuries to Next to Teeth

Prevention:

Most often, nearby teeth are damaged because the dental implant is placed incorrectly or not far enough from other roots. Bringing about this safety requires placing the implant at least 1 mm away from the neighboring teeth. By examining radiographs and images before the surgery, it becomes easier to avoid root penetration, which, if left unaddressed, can cause many problems (30).

Management:

Whenever surrounding teeth are hurt, the resulting outcome will vary according to the good condition. In the longer term, the majority of injured teeth continued to function, but some had to be treated by a root canal and a small number had to be taken out by extraction. While that is the case, more than ninety percent of teeth affected were

preserved, meaning that many cases can be made stable and kept healthy for a long time (30).

11.7. Lack of primary stability:

Prevention:

Strong primary stability is required, since it directly determines how well the implant osseointegrates. If the bone density, volume or drilling process is not right, the screws may not be stable. Before surgery, clinicians should ensure that the bones are properly checked to avoid infections. When implants are designed for optimal strength and surgery is done according to bone type, enough stability is achieved, especially in the back of the upper jaw (31).

Management:

If additional stability at the implant site is not achieved, healthcare professionals might need to delay putting loading on the implants or use other treatments such as placing longer and wider devices or bone compressing. In particular circumstances, it may be necessary to place the implant after a temporary period or use supporting techniques for the implant to heal in bone (31).

11.8. Mandibular Bone Fracture

Prevention:

Sometimes, mandible fractures can happen while conducting dental implants if the bone is weak. If several implants are fixed in the front of the mouth, the bone there can reach its stress limit. Preoperative tests that measure bone mineral density and use X-rays should not be overlooked. When bones are not very strong, the implantation process can be spaced out, and certain implant factors, such as placement and length, can be adjusted to help minimize pressure (32).

Management:

Should a fracture happen during surgery, it could show signs of sudden pain, reduced ability to move the jaw or spontaneous bleeding. If the injuries are severe, first stabilize the patient, then do surgery and observe closely afterwards. If the condition is quickly treated and the patient gets proper support, the final outcomes may be good (32).

11.9. Accidental Displacement into the Maxillary Sinus.

Prevention:

When implants are put into the back part of the upper jaw, sometimes they can move into the maxillary sinus due to regions with a short or brittle bone height. Telltale reasons for sinus perforation are deficient imaging before surgery, applying too much pressure when inserting the tube, and not properly identifying the sinus structures. To avoid this complication, doctors must check the density of the surrounding bone, carefully drill, and use as little force as needed at the tip of the implant (40).

Management:

When this happens during an operation, it should be quickly recognized. If the fixation of the implant is weak and it penetrates the sinus cavity during surgery, the orthopedic surgeon may need to remove it through special or standard methods. Placement, dimensions and condition of the implant are main consideration for making the choice. If sinus problems are found early and treatment begins, it can help preserve nearby areas and avoid complications (40) .

11.10. Sinus Floor Perforation

Prevention:

Schneiderian membrane perforation can occur while elevating the sinus in the back part of the maxilla. Such problems arise when the sinus membranes are thinner, septae are found, and the bones are narrow. Too much force or having poor visibility of the membrane during delivery increases the risk of tearing. Imaging the heart before surgery and using the right technique allows doctors to prepare for unusual features and protect the membranes (34).

Management:

In some cases, perforations are hidden from sight and may later cause instability in the implant and difficulty with healing. If the injury is spotted, the surgeon may halt the surgery or place a membrane that aids healing. Postoperative monitoring helps identify any early issues that may occur (34).

11.11. Nasal Floor Perforation: Preventing Problems and Handling Management

Prevention:

Sometimes, a hole forms in the floor of the nose in the anterior maxilla, particularly when the remaining bone above it is short. This might occur when a doctor solely uses 2D imaging, as this technique can be misleading about how far and at what angle the osteotomy was performed. Expert planning of the procedure in 3D helps prevent drilling into the nasal cavity, which is easy to do when the cortical bone is thin (35).

Management:

When the nasal floor is perforated, the first symptoms can be so mild that they go unnoticed. Management of an implant includes regularly evaluating its placement and finding any signs of discomfort or unexplained sinus issues. In certain cases, the restorer needs to choose between revising and removing the implant(35).

Table 3: Summary of other Intraoperative Complications

Complication	Prevention	Management
Infection	Aseptic technique; control soft tissue trauma and surgical duration; treat preexisting lesions. (3)	Irrigate site; remove contaminants; ensure hemostasis; postpone implant if needed. (3)
Flap Design Errors	Select flap based on site anatomy and access needs. (39)	Correct design intraoperatively; ensure gentle closure. (39)
Thermal Bone Damage	Control drill speed, pressure, and cooling. (27)	Cool down; relocate or postpone implant if severe.
Implant Mispositioning	Use digital planning and surgical guides. (28)	Adjust prosthetics or remove implant; early detection is key. (28)
Aspiration/Ingestion	Use throat gauze, safety ligatures, proper patient positioning. (29)	Radiographic verification; removal via bronchoscopy; ICU monitoring. (29)
Injury to Adjacent Teeth	Maintain ≥1 mm distance from roots; pre-op imaging. (30)	Root canal or extraction if needed; most cases are manageable. (30)
Lack of Primary Stability	Assess bone density; use optimal implant and technique. (31)	Delay loading; use wider/longer implants or bone grafting. (31)
Mandibular Fracture	Evaluate bone health pre-op; avoid stress overload. (32)	Stabilize, surgery if needed; monitor post-op. (32)

Implant Displacement (Sinus)	Assess bone density, drill gently, identify sinus walls. (40)	Prompt recognition and surgical retrieval. (40)
Sinus Floor Perforation	Visualize membrane; avoid excessive force; CBCT guidance. (34)	Stop procedure or place membrane; monitor healing. (34)
Nasal Floor Perforation	Avoid overdrilling; use 3D imaging. (35)	Evaluate implant; consider revision/removal. (35)

12. Early Postoperative Complications

12.1. Infection

Patients can experience implant infection very soon after surgery. Usually, this complication starts a few days following surgery and results in swelling, some redness, pain, and purulent discharge. They happen due to bacteria being present during or shortly after the procedure. Sometimes, infections interrupt the body's healing process and may result in premature failure of the implant (41).(42)

12.2. Edema

Following implant surgery, edema is a common early effect that usually reaches its worst around 48 to 72 hours, causing swelling around the site. The more invasive a surgical procedure is, the more edema there will be because the time spent operating and bone or soft-tissue handling increases fluid buildup. In these more serious situations, too much swelling can increase a patient's discomfort, limit the movement of the jaw, and slightly affect how the bone structure is remodeled which could impact the results over time(37).

12.3. Ecchymoses and hematomas

Ecchymoses and hematomas can develop in the first days after surgery as a result of bleeding in the operated area. Discoloration or blood accumulation in the eyes occurs in these events and happens more often to those with sensitive blood vessels or other health problems. In some cases, serious hematomas may tighten the tissues and prevent the person from healing as expected (37). (4)

12.4. Emphysema

In some cases, subcutaneous emphysema may occur when air is introduced into the skin during or right after surgery. Often, this situation results upon using compressed air tools or when air pressure inside the mouth changes quickly. Medically, the signs of emphysema are a sudden bulge and the sensation of crunching when touched (37).

Annibali et al. (2008) and Mester et al. (2020) reveal this information.

12.5. Bleeding

When the surgical site involves the front part of the lower jaw, bleeding after surgery can have serious consequences. During the planning stage of implant placement, the vascular problem usually occurs if the bone of the tongue is broken through. When the area bleeds, the floor of the mouth may become swollen and, in severe instances, put nearby structures at risk (43).

12.6. Flap Dehiscence

Mucosal margin re-exposure of the implant was found to be the most common minor issue recorded by the Clavien–Dindo review of implant surgery cases. Common risk factors were tension on the flap, thin or poorly supplied skin flap and any problem with the initial closing. With the collar no longer covering the implant site, bacteria can reach it, potentially hurting its chance of healing and helping the implant succeed (42).

Both Froum (2018) and Dilaver et al. (2020) discuss the essence of platforms.

12.7. Sensory Disorders

After an implant is placed, harm to the inferior alveolar, mental or nasopalatine nerves can bring about sensory disturbances, from full loss of sensation to discomfort and sometimes tingling in the lower lip, chin and close by areas. When the nerve is damaged by an implant, the injury is often worse compared to damage in other dental medical procedures. They occur most often around osteotomies in the first bicuspid's anterior mouth loop, the land near the second premolar and mental foramen, the atrophic mandible's rear and the zone in front of the nasopalatine canal in the maxilla. (44).

13. Prevention and management of Early Postoperative Complications:

13.1. Infection

Prevention

Aseptic surgery conditions are very important to prevent early infection caused by bacteria after an implant procedure. Sterile dressings are used, the patient's skin and mouth are scrupulously cleaned and antibiotics are given before surgery. Most often, only a single preoperative dose of amoxicillin is given because it helps reduce the frequency of early infections around implants. These methods are described in the clinical review written by Annibali et al (37).

Management

Health professionals should give treatment as soon as the infection is detected. According to Zarchini et al., the treatment is usually amoxicillin–clavulanic acid for a week to ten days, with additional use of chlorhexidine mouthwash to control microbes around the infection. For more serious cases where pus or infection continues, a flap must be raised again, any necrotic tissues need to be removed and the wound can be cleaned carefully to encourage recovery and lower bacteria. Zarchini et al. explain this complete protocol in greater detail(41).

13.2. Edema

Prevention

The first part of stopping postoperative swelling is to use careful surgical practice. In Annibali et al.'s view, making the procedure fast, around 20 minutes, and using a light touch when elevating soft tissues results in less tissue trauma, as this often brings on edema. In addition, using a cold compress right after surgery and providing a single shot of corticosteroids during that time helps decrease inflammation even more. According to Annibali et al., the techniques described above reduce the amount of face swelling in the days right after implant placement (37).

Management

Most commonly, swelling after eye surgery is at its highest point between two and three days after surgery. During this time, using a cold compress lessens the amount of fluid that leaks from the blood vessels. At the same time, NSAIDs which are analgesics, are recommended to control both pain and inflammation in the case of sprains. Most of the time, the swelling gets better little by little and does not require a trip to the surgeon. It is necessary to check the patient because edema can sometimes point to an infection or a hematoma. Letting patients know what to do following surgery promotes better recovery and cuts down on worry. They have outlined the progression of clinical aspects of coeliac disease in great detail (37).

13.3. Ecchymoses & Haematomas

Prevention

With patients who are operated on for long periods or who use anticoagulants, being extra gentle with the soft tissues helps prevent injury and lessen bleeding under the lining of the mouth. Keeping the flap and wound free from unnecessary changes and applying firm pressure on the outside of the area after closing it commonly helps prevent bleeding under the skin. Placing ice on the area for five minutes or more after surgery can constrict your blood vessels and lower the amount of bruising you experience. The details of these strategies are covered in the clinical observations of Annibali et al(37) .

Management

It is common for simple bruising after implant surgery to disappear within a period without special care. But if a hematoma grows large, and becomes firm or painful, quicker and more thorough care is recommended. If you find yourself on a plane, draining some fluid usually solves the problem and helps with recovery. In addition, applying heparinoid cream topically may lower swelling and improve blood flow to help clear localized blood buildup. These methods are explained by Misch (20).

13.4. Emphysema

Prevention

Following oral surgery, the chance of subcutaneous emphysema can be reduced by adhering to some precautions. You should avoid air-driven handpieces, since they may push air through open or fragile openings in the tissue. Tightly sealing the flap during closing reduces the chance of air getting in. Patients should be told to not drink through straws, smoke or blow their noses for at least two days following the surgery. Preventive measures are explained in the Annibali et al. study (2008) (37).

Management

Usually, subcutaneous emphysema will improve on its own without the need for surgical treatment. For mild cases, you can massage the affected side and put an ice pack to help release the air and lower swelling. If the infection appears to be worsening by becoming redder, warmer or causing higher fever, antibiotic therapy could help stop any complications. Within a week, the symptoms usually go away. Annibali et al. (2008) describe what clinical course to expect in this disease (37).

13.5. Bleeding

Prevention

Before any surgery, experts must pay close attention to planning to decrease the risks of postoperative bleeding. The position of main blood vessels should also be checked radiographically, especially below the mouth or near the lingual artery which are often

complicated areas. No tension should be added to tissue while closing the flaps during surgery to ensure local blood vessels are not damaged. This helps keep the implant area safe and lessens the chances of bleeding following surgery. In 2008, Annibali et al. said these are the main recommendations (37).

Management

To control bleeding after an operation, first press hard and steadily on the wound site with gauze and use an additional hemostatic agent if one is available. If pressing does not stop the bleeding, it may be necessary to return to the surgical site to look for and tie off the blood vessel. If there is a lot of bleeding from the mouth that results in major swelling, or blocking breathing, urgent help is necessary. This protocol is explained in the study done by Annibali et al. (2008)(37) .

13.6. Flap Dehiscence

Prevention

A strong soft tissue seal around implants helps them succeed over the long run. A reliable method to reduce flap dehiscence is to make sure the flap is wide and under no tension. This improves the amount of healthy coverage over the wound and cuts down on pressure at the wound edges. It is important to put off loading the implant because early functional pressure on budding tissues can cause the wounds to separate too early. You can find information on these preventative strategies in the findings by Annibali et al (37).

Management

The treatment for flap dehiscence changes with the degree and size of the opening. In most cases, little or no surgery is necessary for small separations; simply clean the area with chlorhexidine twice every day to help keep it infection-free. If the incision becomes larger, a surgical correction might be needed. The wound edges are refreshed to stimulate cell attachment and the area is then sutured very carefully to ensure a good seal. When much of the implant or nearby graft becomes exposed, a new soft tissue graft may have to be performed. The graft gives biological support, promotes the return of blood vessels, and restores the mucosal seal. The authors found that these clinical approaches are outlined in detail by Annibali et al (37).

13.7. Sensory Disorders

Prevention

To be safe, the mandibular canal should not be any closer than 2 mm to the implant location and this must be seen on preoperative dental X-rays. It helps make sure the inferior alveolar nerve is not damaged during treatment. Also, making use of depth-control features on surgical drill tips prevents making cuts that are too deep. How to perform additional radiographic and surgical safety activities is described by Annibali et al (37).

Management

Treatment of neuropraxia which causes temporary numbness or tingling, is generally conservative. The area affected by nerve damage should be monitored often and patients have to be assured that nerve recovery regularly takes months. Continuous examinations are necessary to notice any changes in the senses. When symptoms don’t improve or change (such as with the appearance of dysesthesia or worsening hypoesthesia), more tests are needed to find out how involved the nerves might be and to determine if a specialist is required. The suggestions are given in the clinical reports published by Annibali et al . (37)

Table 4 : summary of early posoperative complications, prevention and management

Complication	Prevention	Management
Infection	Maintain strict aseptic conditions, preoperative skin/mouth disinfection, single-dose amoxicillin prophylaxis. (37)	7-10 days of amoxicillin-clavulanic acid, chlorhexidine mouthwash, debridement in advanced cases. (41)
Edema	Minimize surgical trauma, keep surgery under 20 minutes, cold compress immediately, perioperative corticosteroids. (37)	Cold compresses, NSAIDs, patient education; monitor for infection or hematoma. (37)
Ecchymoses & Hematomas	Gentle soft tissue handling, minimize surgery time, apply ice post-op to reduce bruising. (37)	Usually self-limiting. Drain if large or painful. Heparinoid cream may aid resorption. (20)
Emphysema	Avoid air-driven handpieces, ensure flap closure, instruct patients to avoid straws/smoking/blowing nose. (37)	Usually resolves spontaneously. Massage, ice packs. Antibiotics if infection suspected. (37)
Bleeding	Radiographic planning of vascular anatomy, gentle flap closure without tension. (37)	Apply firm pressure and hemostatic agents. Reoperate if uncontrolled or obstructive bleeding.
Flap Dehiscence	Tension-free flap design, delay loading to avoid early stress on wound edges.	Small: chlorhexidine rinse. Larger: surgical resuturing

		or soft tissue graft if exposure is extensive. (37)
Sensory Disorders	Maintain ≥2 mm distance from mandibular canal, use depth control on drills, confirm with imaging. (37)	Monitor nerve recovery, reassure patient. Reassess if dysesthesia/hypoesthesia worsens or persists. (37)

14. Late Postoperative Complications:

14.1. Perforation of the Mucoperiosteum

An extensive incision of the peri-implant flap or thinning after flap uncovering may result in a narrow part of the implant collar not being adequately covered. A bit of this exposure can become a plaque trap, and with time, a shallow radiolucent hole may show up in the crestal bone, revealing ongoing soft-tissue irritation and early bone damage(37). **(Annibali et al., 2008)**

14.2. Maxillary Sinusitis

It is known from research that infection of the maxillary sinus can develop months after dental implants or graft particles are used. According to Beck-Broichsitter et al. (2020), having a hole in the Schneiderian membrane during sinus-lift surgery made it three times more likely that the sinus infection would be delayed and the implant lost. In most cases, patients attend appointments after some time, displaying unilateral stuffiness, pus from the nose, and reduced bone right above the implant (34).

14.3. Mandibular Fractures

It is rare, but pathologic fractures of the mandible can exist years after numerous implants are installed in only one visit. With time, experts have found that chewing repeatedly on such teeth makes cracking start around the close fixtures in the crown and moves down to fracture the weakened outer plate anywhere from six months to two years after loading (32)

14.4. Failed Osseointegration & Advanced Bony Defects

If osseointegration does not happen or bone defects are serious, the peri-implantitis lesion typically shows greater loss of bone than usual. When measured in radiographs, a loss of 2 mm or more in the crystal bone after loading the prosthesis or when no baseline imaging exists, a bone resorption greater than 3 mm along with pockets measuring 6 mm or more, pinpoints advanced bone defects. Because bone loss takes place unevenly and fast, it exposes a lot of the implant and makes its stability questionable. (45). In a research paper from Scarano et al. (2023), it says…

15. Prevention and management of Late Postoperative Complications:

15.1. Perforation of the Mucoperiosteum

Prevention

To ensure the mucosa is protected during the second implant surgery, you should raise a flap that spares 2 mm of healthy, keratinized tissue. If there is not enough thickened soft tissue, connective tissue, or a free-gingival graft is added ahead of prosthetic construction, as the mucosal seal must be strengthened. Another step is to precisely adapt the abutments and polish the implant collar to prevent micromovement and keep plaque out which maintains soft tissue quality (46).

Management

If mucoperiosteal dehiscence is found, remove tissue and clean and disinfect the exposed implant. The granulation tissue must first be removed, with a covering graft added to close the area completely. Advice is given to patients to clean their oral cavity twice a day with 0.12% chlorhexidine after their operation. Antibiotics should only be given when it is clear there is an infection. Regular visits are necessary until the soft tissue covers the implant completely and peri-implant probing depths do not change.)(46)

15.2. Maxillary Sinusitis

Prevention

To avoid getting maxillary sinusitis following treatment, surgeons need to be very careful during the sinus lift. To prevent perforation, it is important to elevate the Schneieran membrane slowly and easily. Should the membrane become ruptured during elevation, cover the sinus promptly with a collagen barrier for cavity protection and help regenerate the tissue. Doing this saves the sinus lining and aids the area where the tissue was grafted. It is important to avoid using excessive instrumentation and to use only modest pressure to help prevent problems with the sinus walls. Preventive approaches are provided by Misch (2008) and incorporated into clinical protocols by Beck-Broichsitter et al. (2020) (20,34).

Management

Maxillary sinusitis that arises after a sinus lift will need treatment based on the number of symptoms you experience. Most often, if someone has unilateral nasal discharge, facial pain, or swelling, they are given amoxicillin-clavulanate antibiotics for 10 to 14 days and nasal decongestants to provide relief and help drain the nasal passages. If the infection remains or symptoms stay the same, seeing if X-rays can detect blockages is sometimes necessary. When medicine does not work, endoscopic sinus surgery may be recommended. By removing only a small section of inflamed or blocked tissue, it helps restore correct sinus function. The approach is backed by the studies of Misch (2008) and Beck-Broichsitter et al. (2020) (20,34).

15.3. Mandibular Fractures

Prevention

Because severely atrophic mandibles are fragile, special attention must be given during the planning of implants to prevent any fractures. Placing fewer implants at the same time is an important way to protect against implant failure. If the bone below the tooth is fragile, it is best to pick a short and narrow implant. Expert clinicians should make sure there is at least 1 mm of cortical bone on both the buccal and lingual sides for the mandible to remain strong before any implant is inserted. Recommendations for this issue are explained in Misch (2008) and Andreucci et al. (2024)(20,32).

Management

If a crack in the jaw forms just after implant placement and involves the implant sites, the first step is to immediately remove those implants. It helps by ensuring there is no danger to the bones during their healing process. Holding the jaw bones in their correct place requires titanium plates of high rigidity attached to the fracture and held steady with bicortical screws. After their fracture has been fixed and made stable, patients are recommended to eat soft foods for about four months to reduce strain on the area and help it heal correctly. These procedures are mentioned in the protocols by Misch (2008) and Andreucci et al. (2024) (20,32).

15.4. Failed Osseointegration and Advanced Bony Defects

Prevention

Preventive methods are designed to stop peri-implant inflammation and keep the bone around the implant healthy. You need to have a planned recall system, with professionals cleaning your mouth and teaching patients how to maintain low plaque. Debriding the exposed area on the root or implant surface and adjusting the bite to avoid strong biting forces, is advisable in the beginning of maintenance. Taking this approach cuts down the chance of bacteria taking hold and occluding teeth causing thinning of the jaw and implant issues. These points are endorsed by both Annibali et al. and Scarano et al. (37,45)

Management

If problems including bone defects or unsuccessful osseointegration are found, Scarano et al. (2023) recommend that surgery be done. A full-thickness flap is lifted to expose both the implant and the area on the bone where the injury has occurred. The implant surface is next cleaned using curettes or ultrasonic tools. If it is required, implantoplasty is used to smooth the threads and decrease where plaque may build up. If soft tissue is lost, grafts made from the patient's own connective tissue or substitutes based on collagen may be used to restore fullness and close the wound further. Also, follow-up appointments are set every three months to check healing and to stop any adjacent implants from becoming infected again. The approach is thoroughly described by Scarano et al. (45)

Summary of Late Postoperative Complications: Prevention and Management

Table 5 Summary of Late Postoperative Complications: Prevention and Management

Complication	Prevention	Management
Perforation of the Mucoperiosteum	Raise flap preserving 2 mm keratinized tissue; consider grafting if tissue is thin; adapt abutments precisely; polish implant collar. (46)	Remove tissue and disinfect; remove granulation tissue; place covering graft; chlorhexidine rinse; antibiotics only if infection is present; regular follow-up. (46)
Maxillary Sinusitis	Gentle elevation of Schneiderian membrane; use collagen membrane if perforated; avoid excessive pressure and instrumentation. (20,34)	Antibiotics (amoxicillin-clavulanate) for 10–14 days; nasal decongestants; imaging if persistent; endoscopic sinus surgery if needed. (20,34)
Mandibular Fractures	Avoid multiple simultaneous implants in atrophic mandibles; use short/narrow implants; ensure 1 mm cortical bone on buccal and lingual sides.	Remove implants at fracture site; stabilize with titanium plates and bicortical screws; recommend soft diet for 4 months. (20,32)
Failed Osseointegration and Advanced Bony Defects	Implement recall system; professional cleaning; oral hygiene education; early debridement; occlusal adjustment. (37,45)	Raise full-thickness flap; debride and clean implant; perform implantoplasty if needed; soft tissue grafting; monitor healing every 3 months. (37,45)

16. Technological Innovations in Managing Surgical Risks in Implantology

Recent advancements in digital technology and artificial intelligence are revolutionizing implant dentistry. As highlighted in a 2023 scoping review, Elgarba, Fontenele, and Tarce emphasized how AI-based systems and digital workflows allow clinicians to anticipate risks, improve planning precision, and deliver more predictable outcomes tailored to each patient's anatomy (47).

16.1. Pre-operative Risk-Mitigation Technologies

Cone-Beam CT & Virtual Planning

A comprehensive digital workflow has proven to significantly enhance precision in implant planning, especially for edentulous patients. By integrating Cone-Beam Computed Tomography (CBCT) with intraoral scanners, clinicians can obtain highly detailed representations of patient anatomy, including critical structures such as the maxillary sinus and mandibular canal. Jung et al. describe how CBCT data is aligned with digital scans of existing dentures or temporary prostheses using planning software, enabling the creation of surgical guides that mirror the patient’s anatomy with high fidelity. This virtual planning not only improves preoperative visualization but also facilitates accurate prosthesis design and reduces surgical deviations, thereby minimizing the risk of intraoperative complications. Such a system supports fully digital prosthodontic workflows, leading to greater safety and predictability during implant placement(48) .

Artificial-Intelligence Prediction

Artificial intelligence is becoming an integral part of modern implant dentistry by providing powerful tools for diagnostic support and outcome prediction. Advanced AI models can process large sets of clinical and systemic variables—including HbA1c levels, smoking history, bone density, and trabecular structure—without human intervention. These systems assist clinicians by identifying patterns that may not be immediately visible through conventional assessment. In one notable example reviewed in the literature, an AI model evaluated data from 1,200 implants and successfully predicted

implant outcomes with a sensitivity of 89% and a specificity of 85% within six months. When high-risk individuals are identified early in the treatment planning stage, surgical protocols can be adapted accordingly. These adjustments may include selecting more robust grafting materials, delaying implant placement, or tailoring loading protocols based on the patient's biological risk profile. In this way, AI not only enhances the precision of risk stratification but also supports the personalization of treatment strategies for better clinical outcomes (49).

16.2. Intra-operative Technologies for Precision and Safety

Guided Surgery Systems

Guided surgery systems like X-Guide and Navident offer surgeons real-time visualization and feedback during implant placement by integrating CBCT scans with navigation tools. This dynamic guidance ensures that the drilling path aligns precisely with preoperative plans. According to Luo et al. (2024), a comprehensive meta-analysis of 500 implants revealed that computer-assisted navigation achieved mean positional deviations of 0.8 mm horizontally, 1.0 mm vertically, and 2.1° angular deviation. These accuracy rates were consistently superior to those obtained through conventional freehand techniques. Furthermore, the study highlighted that these systems enhance intraoperative safety by displaying alerts when the handpiece strays beyond predefined safety zones. This is crucial in preventing iatrogenic damage, particularly near delicate anatomical structures like the inferior alveolar nerve or sinus membrane. Therefore, guided systems are especially valuable in complex or high-risk implant sites, offering a measurable improvement in surgical precision and patient outcomes (50).

Piezoelectric Osteotomy

Ultrasonic waves in piezo-electric devices cut hard mineralized areas of a tooth while preserving soft tissue and limiting damage from heat. The bubbles they produce help clear the visual field and lower the amount of bleeding inside the surgical area. Their study in sheep revealed that 8 weeks after using a 3D-printed bit, the bone-to-implant contact rate was 40 percent greater than that of rotary drills, and osteocyte apoptosis or thermal necrosis was not found. Using the small incision surgical approach, surgeons can avoid

postoperative swelling, ensure solid early healing, and graft adjacent bones without risking damage to surrounding nerves and blood vessels (51).

16.3. Post-operative Monitoring and Early Intervention

Smart Dental Implants

Smart dental implants introduce a new era in dental care by combining traditional prosthetic function with advanced diagnostic capabilities. These implants are equipped with miniature embedded sensors that can detect changes in mechanical forces—such as pressure from biting or occlusal overload—as well as subtle temperature variations around the implant site. The detection of these signals is crucial because such changes may reflect the early development of peri-implant inflammation, bone loss, or biomechanical stress.

By identifying these issues at an early stage, clinicians can act before clinical symptoms or radiographic signs appear, potentially preventing complications like implant failure or peri-implantitis. This technology enables continuous, passive monitoring of the implant environment and contributes to a more personalized approach to follow-up care. It also reduces the need for invasive examinations or reliance on patient-reported symptoms, which are often subjective. As the system is designed to alert clinicians to deviations from normal conditions, it enhances clinical precision and supports better long-term outcomes (52).

Matrix Metalloproteinase (MMP)-8 Biomarker Kits

The use of aMMP-8 biomarker kits has emerged as a practical, non-invasive method for the early detection of peri-implant disease. These kits analyze sulcular fluid using a rapid point-of-care immunofluorescence test, which can be completed in just five minutes. The active form of matrix metalloproteinase-8 (aMMP-8) is a key indicator of collagen breakdown in inflamed tissues. Detecting elevated levels of this enzyme enables clinicians to identify peri-implantitis before clinical signs are visible. The PerioSafe test has demonstrated strong diagnostic performance, with 88% sensitivity and 92% specificity. Early biochemical detection allows for prompt intervention, such as local antimicrobial therapy or mechanical cleaning, potentially preventing the progression of peri-implant inflammation and improving long-term implant outcomes(53) .

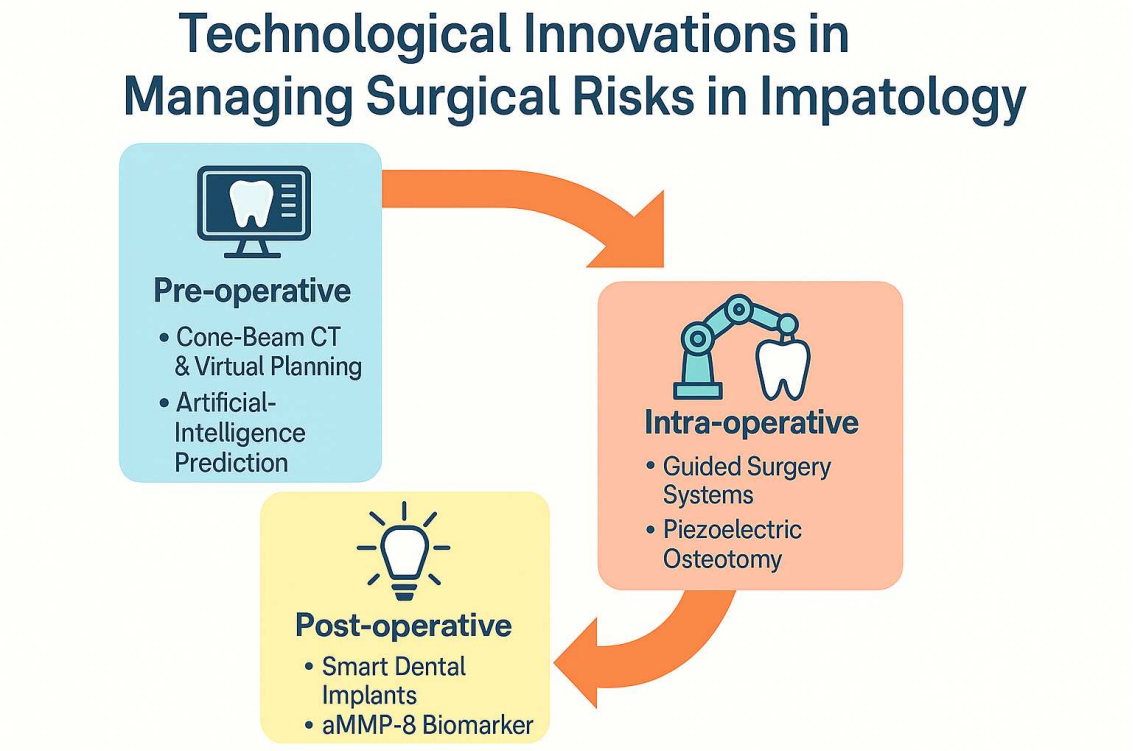

Figure 15 Technological Innovations Across Pre-, Intra-, and Post-Operative Phases in Managing Surgical Risks in Implantology

III. Conclusion

The effective management of surgical complications in implantology stands at the core of successful oral rehabilitation. Throughout this thesis, we have explored a comprehensive framework addressing both prevention and therapeutic strategies across various types of complications, from early-stage infections and sensory disturbances to late-onset bone loss and prosthetic failure. Each complication presents unique challenges, requiring a tailored approach grounded in clinical evidence, meticulous planning, and technological innovation.

The prevention chapters highlighted the importance of proper preoperative assessment, sterile technique, and surgical precision—emphasizing the use of tools such as cone-beam computed tomography (CBCT), dynamic navigation systems, and guided implant surgery. Additionally, modern adjunctive strategies such as AI-based risk prediction and piezoelectric osteotomy were shown to reduce risk by enhancing diagnostic accuracy and surgical safety.

Management strategies were equally essential, with protocols ranging from pharmacologic intervention to surgical revisions, supported by evidence from recent literature. Whether addressing peri-implantitis with flap debridement and implantoplasty or managing mandibular fractures with reconstruction plates and diet modification, the thesis underscores the necessity of early detection, ongoing monitoring, and evidence-based intervention.

Importantly, this work recognizes the clinical utility of emerging technologies, including smart implant sensors and biomarker kits such as aMMP-8, for real-time post-operative monitoring. These tools not only improve patient outcomes but also support a shift toward personalized and proactive implant care.

In conclusion, surgical complication management in implantology requires a dynamic and multidisciplinary approach. Success hinges on integrating clinical experience with evolving technology and continuous patient-specific evaluation. By adopting these principles, clinicians can reduce the incidence of complications, improve implant longevity, and ensure a higher standard of care for patients

IV. REFERENCES

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